

EC155

CO₂/H₂O Closed-Path Gas Analyzer



Table of Contents

PDF viewers: These page numbers refer to the printed version of this document. Use the PDF reader bookmarks tab for links to specific sections.

1. Introduction.....	1
2. Precautions.....	1
3. Initial Inspection	2
4. Overview	2
5. Specifications	5
5.1 Measurements	5
5.2 Output Signals.....	7
5.3 Physical Description.....	8
5.4 Power Requirements	10
6. Installation	10
6.1 Preparation of Vortex Intake.....	11
6.2 Mounting.....	12
6.3 Plumbing.....	16
6.3.1 Flow	16
6.3.2 Pressure.....	16
6.3.3 Filtration.....	17
6.3.4 Plumbing Connections	19
6.3.4.1 Sample Intake.....	19
6.3.4.2 Pump.....	20
6.3.4.3 Zero and Span.....	20
6.4 Wiring and Connections.....	20
7. Settings	24
7.1 Factory Defaults.....	24
7.2 Details	25
7.2.1 Bandwidth.....	25
7.2.2 SDM Address.....	25
7.2.3 Unprompted Output	25
7.2.4 Unprompted Output Rate	26
7.2.5 RS-485 Baud Rate.....	26
7.2.6 Analog Output.....	26
7.2.7 <i>ECMon</i> Update Rate	26
7.2.8 Sonic Transducer Shadow Correction.....	26
7.2.9 Temperature Sensor	27
7.2.10 Fixed Temperature Value.....	27
7.2.11 Heater Manual Control.....	27
7.2.12 EC100 Barometer.....	28
7.2.12.1 Pressure Gain.....	28
7.2.12.2 Pressure Offset	28

7.2.12.3	Fixed Pressure Value	28
7.2.13	EC155 Sample Cell Pressure Sensor.....	28
7.2.14	Differential Pressure	28
7.3	<i>ECMon</i>	28
7.4	<i>Device Configuration Utility</i>	31
8.	EC100 Outputs.....	31
8.1	SDM Output.....	32
8.2	USB or RS-485 Output	32
8.3	Analog Outputs	34
9.	Maintenance.....	35
9.1	Routine Maintenance	35
9.2	Intake Cleaning and Filter Replacement	35
9.2.1	Vortex Filter Replacement and Vortex Intake Cleaning	35
9.2.1.1	Replace Vortex Filter	36
9.2.1.2	Cleaning the Bypass Tubing and Vortex Chamber	37
9.2.2	Inline Intake Filter Replacement.....	39
9.3	Cleaning Analyzer Windows	40
9.4	Zero and Span	43
9.5	Replacing the EC155 Desiccant/CO ₂ Scrubber Bottles.....	46
9.6	Factory Recalibration	47
10.	Data Collection and Data Processing	48
10.1	Data Collection and Processing with <i>EasyFlux DL</i>	48
10.2	Datalogger Programming with <i>CRBasic</i>	50
10.2.1	EC100() Instruction.....	50
10.3	EC100Configure() Instruction.....	53
10.3.1	ConfigCmd 11 Zero-and-Span Control.....	55
10.3.2	ConfigCmd 18 Heater Voltage.....	55
10.4	Example CRBasic Program.....	56
11.	Theory of Operation	56
Appendices		
A.	Filter Bandwidth and Time Delay.....	A-1
B.	Useful Equations	B-1
C.	EC155 Sample Cell and Intake Maintenance	C-1
C.1	Cleaning Sample Cell.....	C-1
C.2	Cleaning Intake Tube	C-1
C.2.1	Detaching the Vortex Intake	C-1
C.2.2	Dust Blowout	C-3
C.2.3	Solvent Flush	C-4
D.	CSAT3A Orientation	D-1
D.1	Determining True North and Sensor Orientation	D-1

D.2	Online Magnetic Declination Calculator.....	D-2
E.	Safety Data Sheets (SDS).....	E-1
E.1	Molecular Sieve, Type 13X	E-1
E.2	Magnesium Perchlorate.....	E-5
E.3	Decarbite	E-12
F.	EC155 Packing Information	F-1

Figures

4-1.	New design CSAT3A (top) and old previous design CSAT3A (bottom)	4
5-1.	Dimensions of EC155 analyzer with vortex intake; sample cells with serial numbers 2000 and greater	9
5-2.	Dimensions of the older-design EC155 analyzer; sample cells with serial numbers less than 2000	10
6-1.	Bypass tube and filter assembly	12
6-2.	Exploded view of the EC155 and bypass tube and filter assembly	12
6-3.	Exploded view of mounting newer design EC155 gas analyzer (EC155 sample cell serial numbers 2000 and greater) and CSAT3A sonic head (CSAT3A serial numbers 2000 and greater); cables not shown	13
6-4.	Exploded view of mounting older design EC155 gas analyzer (EC155 sample cell serial numbers less than 2000) and CSAT3A sonic head (CSAT3A serial numbers less than 2000).....	14
6-5.	EC100 enclosure mounting bracket mounted on a vertical mast (left) and a tripod leg (right)	15
6-6.	Exploded view of mounting the EC100 enclosure	16
6-7.	External views (top) and cross-sectional views (bottom) of the vortex intake.	17
6-8.	Cross-sectional view of vortex chamber and respective air flow	18
6-9.	Screen located at underside of vortex intake.....	18
6-10.	End view of EC155 analyzer showing ports for pump outlet (vortex bypass tubing and filter assembly not shown) and zero-and-span intake	19
6-11.	EC100 electronics front panel. The left figure shows the panel as it is shipped from the factory (enhanced barometer shown). The right figure shows the panel after the user has done all the wiring and made all connections (basic barometer used).	21
6-12.	Bottom of EC100 enclosure	21
6-13.	Connection for CSAT3A in EC100 module.....	22
7-1.	Angle θ is defined as the angle between the three-dimensional wind vector, \mathbf{U} , and the vector component parallel to the sonic path, \mathbf{U}_i	27
7-2.	Main window of ECMon.....	29
7-3.	Setup window in ECMon. Note that a few of the most rarely used settings have been omitted in Setup window of ECMon for convenience. To access all settings, use Device Configuration Utility.....	30
7-4.	ECMon Status window	30
8-1.	An example of USB data output in terminal mode	33
9-1.	The vortex filter assembly includes a 25 μm particulate filter with 1/4-in Swagelok nuts on either side.....	36

9-2. Exploded image of vortex intake with bypass tube pulled from bypass tube sleeve, and bypass tube sleeve pulled back away from vortex chamber.....37

9-3. Pulling gently backwards on the vortex chamber will release it from the intake end piece. The vortex inlet heater cable remains attached.37

9-4. A damp paper towel or cloth used to floss and clean inside surfaces of vortex chamber38

9-5. The underside of the intake of the older design sample cell showing the inline filter with rain diverter in black40

9-6. The EC155 analyzer with the top shell open.....41

9-7. Thumbscrews above sample cell allowing latches to be spun from position A to position B, freeing struts of analyzer.....41

9-8. EC155 analyzer and sample cell with shell top open42

9-9. Analyzer removed from sample cell and shell42

9-10. ECMon Zero/Span window.....45

9-11. Replacing the source housing desiccant/scrubber bottle (replacement bottles purchased in or after July 2017 may appear different than in the figure)47

9-12. Replacing the detector housing desiccant/scrubber bottle (replacement bottles purchased in or after July 2017 may appear different than in the figure)47

10-1. Compass coordinate system, compass wind direction is 200°. The sonic azimuth of the anemometer is 270°49

10-2. Right-handed coordinate system, horizontal wind vector angle is 70°50

D-1. Magnetic declination for the contiguous United States (2015) D-1

D-2. Declination angles east of true north are subtracted from 360 to get true north..... D-2

D-3. Declination angles west of true north are added to 0 to get true north..... D-2

D-4. Online magnetic declination calculator with inputs and output for Logan, UT D-3

A-1. Frequency and amplitude response of the EC100 filter at various bandwidths..... A-2

A-2. Frequency response comparison of the EC100 10-Hz bandwidth and a 50-msec moving average..... A-3

C-1. Identification of parts for detaching intake with heater cable shown disconnected.....C-2

C-2. Removal of the vortex intakeC-2

Tables

6-1. EC100 SDM Output.....23

7-1. Factory Default Settings.....24

8-1. USB and RS-485 Output Elements33

8-2. Multipliers and Offsets for Analog Outputs.....34

10-1. Output Modes for EC100 Instruction51

10-2. Bits in the Sonic Diagnostic Flag52

10-3. Bits in the Gas Diagnostic Flag.....52

10-4. ConfigCmd Values for Setting and Retrieving Settings.....54

A-1. Filter Time Delays for Various Bandwidths..... A-3

EC155 CO₂ and H₂O Closed-Path Gas Analyzer

1. Introduction

The EC155 is an in-situ, closed-path, mid-infrared absorption gas analyzer that measures molar mixing ratios of carbon dioxide and water vapor, along with sample cell temperature and pressure. The EC155 may be used in conjunction with the CSAT3A sonic anemometer, which measures orthogonal wind components and sonic temperature.

Before using the EC155, please study:

- Section 2, *Precautions* (p. 1)
- Section 3, *Initial Inspection* (p. 2)
- Section 6, *Installation* (p. 10)

More details are available in the remaining sections.

NOTE

In January 2016, new versions of the EC155 sample cell and CSAT3A sonic anemometer were released. An EC155 with the new sample cell has a serial number of 2000 or greater and may easily be recognized by the vortex intake and the yellow label on the sample cell cable (the older version has a white label on the cable). Throughout the manual, the new version is often referred to as the “sample cell with vortex intake” or more simply as the “vortex sample cell”.

The new version of CSAT3A has a serial number of 2000 or greater and is most readily recognized by the narrower mounting stem, instead of the old block style. Although the operation of the old and new designs is the same, there are some differences in features and mounting covered in this edition of the manual.

2. Precautions

- DANGER:
 - The scrubber bottles in EC155 instruments shipped prior to July 2017 contain sodium hydroxide (NaOH) and anhydrous magnesium perchlorate (Mg(ClO₄)₂). If you are handling or exchanging the scrubber bottles (see Section 9.5, *Replacing the EC155 Desiccant/CO₂ Scrubber Bottles* (p. 46)), use the following precautions. Beginning in July 2017, EC155 instruments ship with a 13X molecular sieve instead.
 - Avoid direct contact with the chemicals.
 - Ensure your work area is well ventilated and free of reactive compounds, including liquid water.
 - Store used chemical bottles in a sealed container until disposal.
 - Dispose of chemicals and bottles properly.
 - Safety Data Sheets (SDS) are provided in Appendix E, *Safety Data Sheets (SDS)* (p. E-1). SDS are updated periodically by chemical manufacturers. Obtain current SDS at www.campbellsci.com.

- WARNING:
 - Do not carry the CSAT3A by the arms or by the strut between the arms. Always hold it by the stem, where the upper and lower arms connect. Also, do not carry the EC155 by the intake. Always hold it by the main body.
 - Handle the EC155 carefully. The optical source may be damaged by rough handling, especially while the analyzer is powered.
 - Over-tightening bolts will damage or deform the mounting hardware.

- CAUTION:
 - Grounding the EC100 measurement electronics is critical. Proper grounding to earth (chassis) will ensure maximum ESD (electrostatic discharge) protection and improve measurement accuracy.
 - Do not connect or disconnect the gas analyzer or sonic connectors while the EC100 is powered.
 - The SDM, USB, and RS-485 output options include EC155 diagnostic data. Be aware that the absence of diagnostic data in the analog output option could make troubleshooting difficult and may lead to the user not being aware of potential problems with the instrumentation (see Section 8, *EC100 Outputs* (p. 31)).
 - Resting the analyzer on its side during the zero-and-span procedure may result in measurement inaccuracy.
 - When cleaning the gas-analyzer window, make sure the alcohol and any residual water completely evaporate before proceeding with the zero-and-span procedure (see Section 9.3, *Cleaning Analyzer Windows* (p. 40)).

3. Initial Inspection

Upon receipt of your equipment, inspect the packaging and contents for damage. File damage claims with the shipping company.

4. Overview

The EC155 is a closed-path, mid-infrared absorption analyzer that measures molar mixing ratios of carbon dioxide and water vapor, along with sample cell temperature and pressure. It has been designed specifically for eddy covariance flux measurements and may be used in conjunction with the CSAT3A 3D sonic anemometer head. The analyzer has a rugged, aerodynamic design with low power requirements, making it suitable for field applications.

The EC155 gas analyzer connects directly to the EC100 electronics, which computes real-time CO₂ and H₂O molar mixing ratios of the air inside the sample cell of the analyzer. A CSAT3A sonic anemometer head may also be connected to the EC100.

The EC155 has been designed specifically to address issues of aerodynamics, power consumption, performance during precipitation events, ambient air density fluctuations, temporal synchronicity, and system integration. Its unique design enables it to operate with only 4.8 W power; it has minimal spatial displacement from the sample volume of a CSAT3A sonic anemometer; the EC100 electronics synchronize data from the EC155 and CSAT3A; and the analyzer is easily integrated into the CPEC200 closed-path eddy covariance

system, a turn-key system containing data acquisition and control instrumentation, a sample pump, and optional zero-and-span valve module.

The EC155 vortex sample cell and the new CSAT3A sonic head (denoted by EC155 sample cell and CSAT3A serial numbers 2000 and greater) became available in January 2016. The EC155 has the following enhancements:

- A vortex intake (U.S. Pat. No. 9,217,692) significantly reduces maintenance frequency, especially in dusty or polluted conditions, and preserves high frequency response over time
- A heated inlet and elimination of the inline filter results in increased condensation protection while better maintaining frequency response over time
- More accurate sample-cell pressure measurements are made possible with an absolute pressure sensor in the sample cell
- The new intake remains fully integrated but may be detached or replaced if needed
- Stainless steel sample cell for increased corrosion protection

The new version (top panel) and old version (bottom panel) of CSAT3As are shown in FIGURE 4-1. The new CSAT3A design also has important new features:

- Increased rigidity of the CSAT3A improves long-term accuracy and stability of sonic temperature measurements
- A more streamlined and aerodynamic CSAT3A mounting block



FIGURE 4-1. New design CSAT3A (top) and old previous design CSAT3A (bottom)

5. Specifications

5.1 Measurements

Features

- To compute carbon dioxide, water vapor, and sensible heat fluxes using the eddy-covariance method, the EC155 measures:
 - carbon dioxide mixing ratio
 - water vapor mixing ratio
 - three-dimensional wind speed (requires CSAT3A)
 - sonic air temperature (requires CSAT3A)
 - sample-cell temperature
 - sample-cell pressure
 - barometric pressure

These measurements are required to compute carbon dioxide and water vapor fluxes using the:

- Standard outputs:
 - CO₂ mixing ratio, H₂O mixing ratio
 - gas analyzer diagnostic flags
 - cell temperature, cell pressure
 - CO₂ signal strength, H₂O signal strength
 - differential pressure (difference between ambient and sample cell pressures)
 - air temperature and air pressure (auxiliary sensor inputs)
- Additional outputs with CSAT3A:
 - u_x, u_y, and u_z orthogonal wind components
 - sonic temperature (based on the measurement of c, the speed of sound)
 - sonic diagnostic flags

Compatibility: CR6
 CR1000X
 CR1000
 CR3000
 CR5000

Measurement

Rate: 60 Hz
Output bandwidth^{1/}: 5, 10, 12.5, 20 Hz
Datalogger-prompted output rate: 1 to 60 Hz
Unprompted output rate^{1/}: 10, 20, or 60 Hz

Operating temperature: -30 to 50 °C

Gas analyzer

Measurement precision^{2/}

CO₂ density: 0.2 mg CO₂·m⁻³ (0.15 μmol CO₂·mol⁻¹)
H₂O density: 0.00350 g H₂O·m⁻³ (0.006 mmol H₂O·mol⁻¹)

Factory calibrated range

CO₂^{3/}:	0 to 1000 μmol CO ₂ ·mol ⁻¹
H₂O:	0 mmol H ₂ O·mol ⁻¹ to 37 °C dewpoint
Analyzer temp^{4/}:	-30 to 50 °C
Baro pressure:	70 to 106 kPa

CO₂ performance

Zero max drift^{5/}:	±0.55 mg CO ₂ ·m ⁻³ ·°C ⁻¹ (±0.3 μmol CO ₂ ·mol ⁻¹ ·°C ⁻¹)
Gain drift:	±0.1% of reading·°C ⁻¹ (maximum)
Sensitivity to H₂O:	±5.6 x 10 ⁻⁵ μmol CO ₂ ·mol ⁻¹ H ₂ O (max)

H₂O performance

Zero max drift^{5/}:	±0.037 g H ₂ O·m ⁻³ ·°C ⁻¹ (±0.05 mmol H ₂ O·mol ⁻¹ ·°C ⁻¹)
Gain drift:	±0.3% of reading·°C ⁻¹ (maximum)
Sensitivity to CO₂:	±0.05 mol H ₂ O·mol ⁻¹ CO ₂ (maximum)

CSAT3A sonic measurement precision^{6/}

u_x:	1.0 mm·s ⁻¹
u_y:	1.0 mm·s ⁻¹
u_z:	0.5 mm·s ⁻¹
Sonic temperature:	0.025 °C

CSAT3A sonic accuracy^{7/}

Offset error

u_x, u_y:	< ±8 cm·s ⁻¹
u_z:	< 4 cm·s ⁻¹

Gain error

Wind vector ±5° horizontal:	< ±2% of reading
Wind vector ±10° horizontal:	< ±3% of reading
Wind vector ±20° horizontal:	< ±6% of reading

CSAT3A sonic reporting range

Full scale wind:	±65.55 m/s
Sonic temperature:	-50 to 60 °C

Sample cell sensors^{8/}

Absolute pressure sensor^{9/}

Accuracy:	±1.5 kPa (> 0 °C), increasing linearly to ±3.7 kPa at -30 °C
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Temperature sensor

Manufacturer:	BetaTherm
Model:	100K6A1A Thermistor
Accuracy:	±0.15 °C (-30 to 50 °C)

EC100 Barometer

Basic barometer

Accuracy

-30 to 0 °C:	±3.7 kPa at -30 °C, falling linearly to ±1.5 kPa at 0 °C
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0 to 50 °C:	±1.5 kPa
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Measurement rate:	10 Hz
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Optional enhanced barometer

Manufacturer: Vaisala
Model: PTB110
Accuracy
 -30 to 0 °C: ±0.15 kPa
Measurement rate: 1 Hz

^{1/} user selectable

^{2/} noise rms, assumes:

- 25 °C
- 85 kPa
- 19 µmol H₂O/mol concentration
- 326 µmol CO₂/mol concentration

^{3/} 0 to 3,000 µmol CO₂/mol available upon request

^{4/} -40 to +50 available upon request

^{5/} -30 to 50 °C

^{6/} noise rms

^{7/} assumes:

- -30 to 50 °C
- wind speed < 30 m·s⁻¹
- azimuth angles between ±170°

^{8/} refer to manufacturer's product brochure or manual for details

^{9/} For EC155 sample cells with serial numbers less than 2000, refer to the EC100 Barometer specifications for sample cell pressure accuracy

5.2 Output Signals

Features

EC100 electronics outputs data using:

- SDM
- RS-485
- USB
- Analog out

Digital

SDM (Synchronous Device for Measurement)^{1/}

Data type: FLOAT

Datalogger-prompted output rate: 1 to 60 Hz

RS-485

Data type: ASCII

Unprompted output rate^{2/}: 10, 20, or 60 Hz

Baud rate^{2/}: 1200 to 230400 bps

USB

Data type: ASCII

Unprompted output rate^{2/}: 10, 20, or 60 Hz

Analog (two outputs for CO₂ and H₂O molar mixing ratios)

Voltage range: 0 mV to 5000 mV

Resolution: 76 µV (16 bit)

Update rate: 60 Hz

Accuracy (at 25 °C): ±3 mV

CO₂ mixing ratio equation:	$\mu\text{mol CO}_2/\text{mol} = 211.27 (V_{\text{out}}) - 56.34$
Full scale range:	-56 to 1000 $\mu\text{mol CO}_2/\text{mol}$
H₂O mixing ratio equation:	$\text{mmol H}_2\text{O}/\text{mol} = 11.31 (V_{\text{out}}) - 3.04$
Full scale range:	-3 to 53 $\text{mmol H}_2\text{O}/\text{mol}$

^{1/} Synchronous Device for Measurement. A Campbell Scientific, Inc. proprietary serial interface for datalogger to peripheral and sensor communication. See Section 8.1, *SDM Output (p. 32)*, for details.

^{2/} user selectable

5.3 Physical Description

Internal sample cell

Volume:	5.9 cm ³ (0.36 in ³)
Length:	12.0 cm (4.72 in)
Diameter:	7.94 mm (0.31 in)

Spatial separation between EC155 vortex inlet and CSAT3A sample volume center^{1/}

Total separation:	15.4 cm (6.1)
Longitudinal separation (parallel to sonic x-axis):	15.0 cm (5.9 in)
Lateral separation (parallel to sonic y-axis):	3.2 cm (1.3 in)
Vertical separation (parallel to sonic z-axis):	0.6 cm (0.2 in)

Length of tubing from inlet to internal sample cell^{2/}:	64.5 cm (25.4 in)
Inside diameter of intake sample tubing^{3/}:	2.16 mm (0.09 in)
Vortex intake rain diverter volume:	1.3 mL (0.079 in ³)
Vortex chamber volume:	0.9 mL (0.05 in ³)

Dimensions

Analyzer (analyzer head and sample cell):	42.7 x 7.4 x 10.1 cm (16.8 x 2.9 x 4.0 in)
Length of intake:	38.1 cm (15.0 in)
EC100 electronics:	24.1 x 35.6 x 14 cm (9.5 x 14 x 5.5 in)
Cable length:	3 m (9.8 ft) from analyzer to EC100 electronics

Weight

Analyzer (analyzer head and sample cell)^{4/}:	5.0 kg (11.1 lbs)
CSAT3A^{5/}:	1.2 kg (2.7 lbs)
Mounting hardware:	0.4 kg (0.9 lbs)
EC100 electronics and enclosure:	3.2 kg (7 lbs)

Designed EC100 ingress protection rating:	IP65 (not intended for marine environments)
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Connections

Pump:	3/8 inch Swagelok
Zero/Span:	1/4 inch Swagelok

^{1/} Spatial separation between the original EC155 sample cell and CSAT3A sonic head (serial numbers less than 2000) is as follows: total separation: 16.1 cm (6.3 in); longitudinal separation (parallel to sonic x-axis): 15.2 cm (6.0 in); lateral separation (parallel to sonic y-axis): 3.2 cm (1.3 in); and vertical separation (parallel to sonic z-axis): 4.2 cm (1.7 in)

^{2/} Length of tubing between inlet and sample cell of the original-design sample cell (serial numbers less than 2000) is 85.4 cm (23.0 in)

^{3/} Inside diameter of intake tubing of original-design sample cell (serial numbers less than 2000) is 2.67 mm (0.085 in)

^{4/} Weight of the analyzer with an original-design sample cell and CSAT3A sonic head (serial numbers less than 2000) is 3.9 kg (8.5 lbs)

^{5/} Weight of an original-design CSAT3A head (serial numbers less than 2000) is 1.9 kg (4.1 lbs)

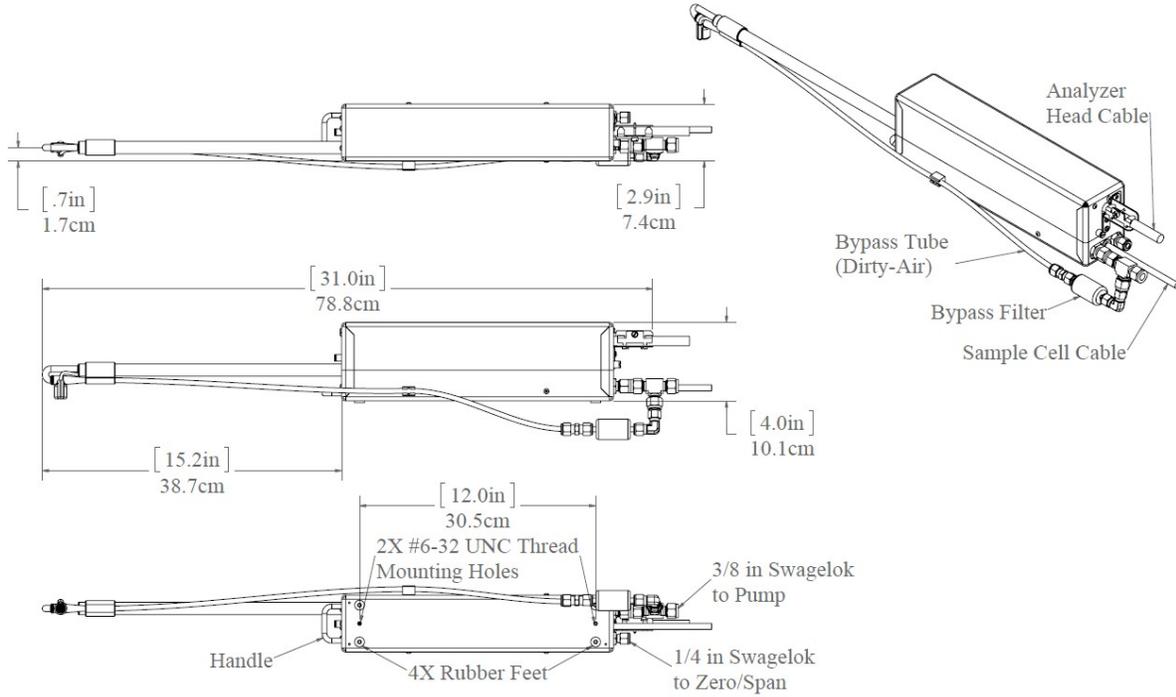


FIGURE 5-1. Dimensions of EC155 analyzer with vortex intake; sample cells with serial numbers 2000 and greater

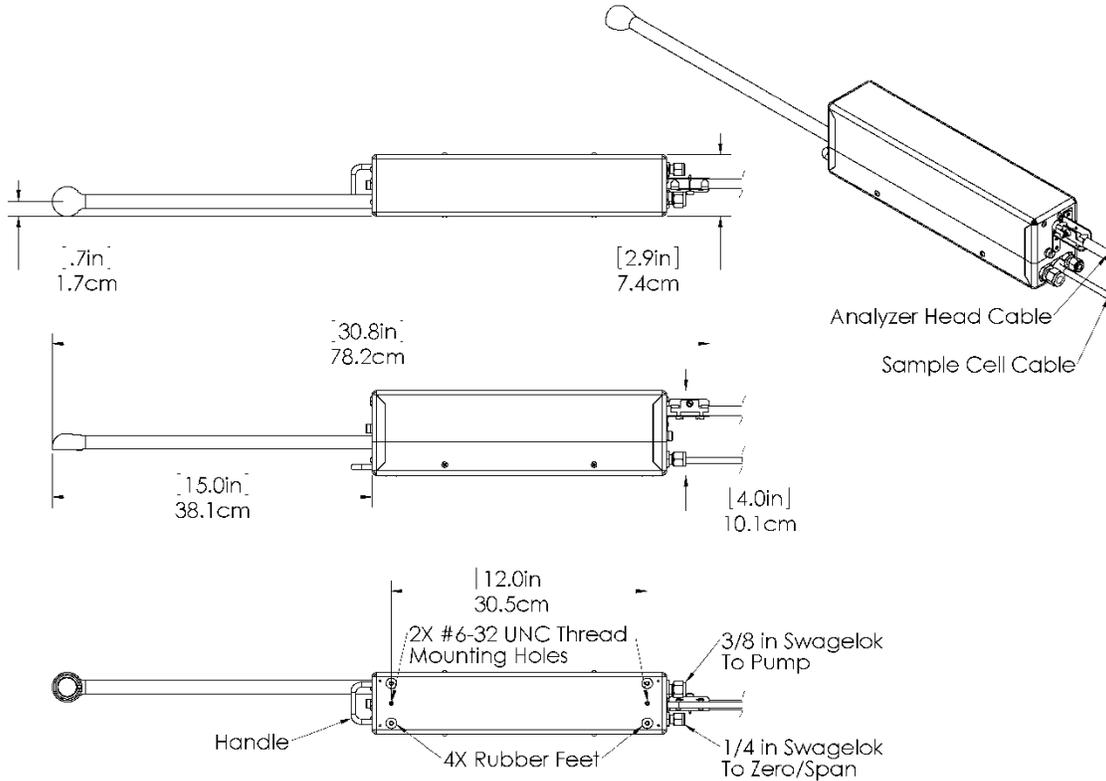


FIGURE 5-2. Dimensions of the older-design EC155 analyzer; sample cells with serial numbers less than 2000

5.4 Power Requirements

Voltage supply:	10 to 16 Vdc
Power at 25 °C including CSAT3A:	4.8 W
Power at 25 °C excluding CSAT3A:	4.0 W
Power at 25 °C in power-down mode (CSAT3A fully powered and EC155 in stand-by):	3.0 W
Power for heated intake:	set by user, 0 to 0.8 W

View compliance documentation at www.campbellsci.com/ec155.

6. Installation

The EC155 is supplied with mounting hardware to attach it to the end of a horizontal pipe of 3.3 cm (1.3 in) outer diameter, such as the CM202, CM204, or CM206 crossarm. The EC155 mounting hardware also accommodates an optional CSAT3A sonic anemometer, which places it at the proper position relative to the intake. The following steps describe the normal mounting procedure for the sample-cell assembly and optional CSAT3A sonic head.

For applications using the EC155 with the CSAT3A sonic anemometer, certain environmental conditions should be considered when choosing an appropriate installation configuration. If the EC155 is coupled with a CSAT3A sonic anemometer and is to be used in a marine environment, or in an environment where it is exposed to corrosive chemicals (for example, the sulfur-containing compounds in viticulture), attempt to mount the EC155 with CSAT3A in a way that reduces the exposure of the sonic transducers of the CSAT3A to saltwater or corrosive chemicals. In marine or viticulture environments, the sonic transducers are expected to age more quickly and require replacement sooner than a unit deployed in an inland, chemical-free environment.

NOTE

Other mounting arrangements are acceptable, but the analyzer must be upright. The bottom of the analyzer has two #6-32, UNC-thread mounting holes for applications that do not use the EC155 mounting platform.

For the sample cell with vortex intake (sample cell serial numbers 2000 and greater) and updated CSAT3A (CSAT3A serial numbers 2000 and greater), complete the steps in Section 6.1, *Preparation of Vortex Intake* (p. 11), before mounting the analyzer. For the original versions of the sample cell and CSAT3A (sample cell and CSAT3A serial numbers less than 2000), skip Section 6.1, *Preparation of Vortex Intake* (p. 11).

6.1 Preparation of Vortex Intake

To prepare the vortex intake for operation, install the bypass tube and filter assembly.

1. Locate the bypass tube and filter assembly packed inside the EC155 carrying case or shipping box. The assembly is shown in FIGURE 6-1.
2. Remove the 3/8-inch Swagelok plug from the fitting labeled **Pump** at the back of the EC155 sample cell and attach the assembly's 3/8-inch Swagelok fitting as shown in FIGURE 6-2.

CAUTION

Overtightening Swagelok fittings can strip threads and result in leaks. If a fitting has been assembled previously such as in the case of the bypass tube and filter assembly, tightening the fitting no more than a quarter turn past finger-tight is adequate.

3. Insert the open end of the bypass tube into the open hole of the vortex's bypass tubing sleeve as shown in FIGURE 6-2. Push the tube into the sleeve about 2.5 cm until it hits the end of the vortex chamber.
4. Push the tube into the clip on the side of the sample cell to hold it securely in place as shown in FIGURE 6-2.



FIGURE 6-1. Bypass tube and filter assembly

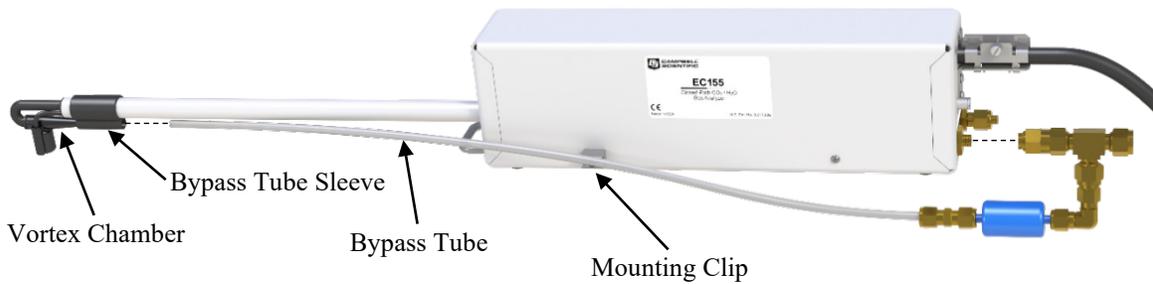


FIGURE 6-2. Exploded view of the EC155 and bypass tube and filter assembly

6.2 Mounting

For the sample cell with vortex intake (sample cell serial numbers 2000 and greater) and updated CSAT3A (CSAT3A serial numbers 2000 and greater), refer to FIGURE 6-3 throughout this section. For the older versions of the sample cell and CSAT3A (sample cell and CSAT3A serial numbers less than 2000), refer to FIGURE 6-4.

1. Mount a CM202, CM204, or CM206 crossarm to a tripod or other vertical structure using a CM210 crossarm-to-pole bracket. The crossarm should be within ± 7 degrees of horizontal to allow the CSAT3A sonic anemometer to be leveled.

WARNING

Do not carry the EC155 by the intake or the CSAT3A by the arms. Always hold the instruments by the body or base.

2. Mount the CM250 leveling mount on the end of the crossarm. Tighten the set screws on the leveling mount.
3. Bolt the EC155 mounting platform to the CM250 leveling mount.
4. Place the EC155 gas analyzer on the mounting platform so the four rubber feet fit into the platform holes, and tighten the captive screws located on the bottom of the platform into the mounting holes on the bottom of the analyzer.
5. If a CSAT3A is being used, mount it on the end of the mounting platform using the captive CSAT3A mounting bolt. The sonic anemometer must be

oriented in a way that it faces the prevailing wind to prevent ‘shadowing’ from the sensor body. See Section 10.1, *Data Collection and Processing with EasyFlux DL*, (p. 48), for additional information about the wind information reported by the sonic coordinate system.

6. Level the assembly by slightly loosening the bolt in the CM250 leveling mount. Adjust the assembly until the leveling bubble on top of the CSAT3A is in the bullseye. Retighten the bolt.

WARNING Over-tightening bolts will damage or deform the mounting hardware.

WARNING Use caution when handling the EC155 gas analyzer. The optical source may be damaged by rough handling, especially when the EC155 is powered.

NOTE If the assembly is to be mounted on a high tower, it can be hoisted using the handle on the front of the analyzer and the holes in the mounting platform.

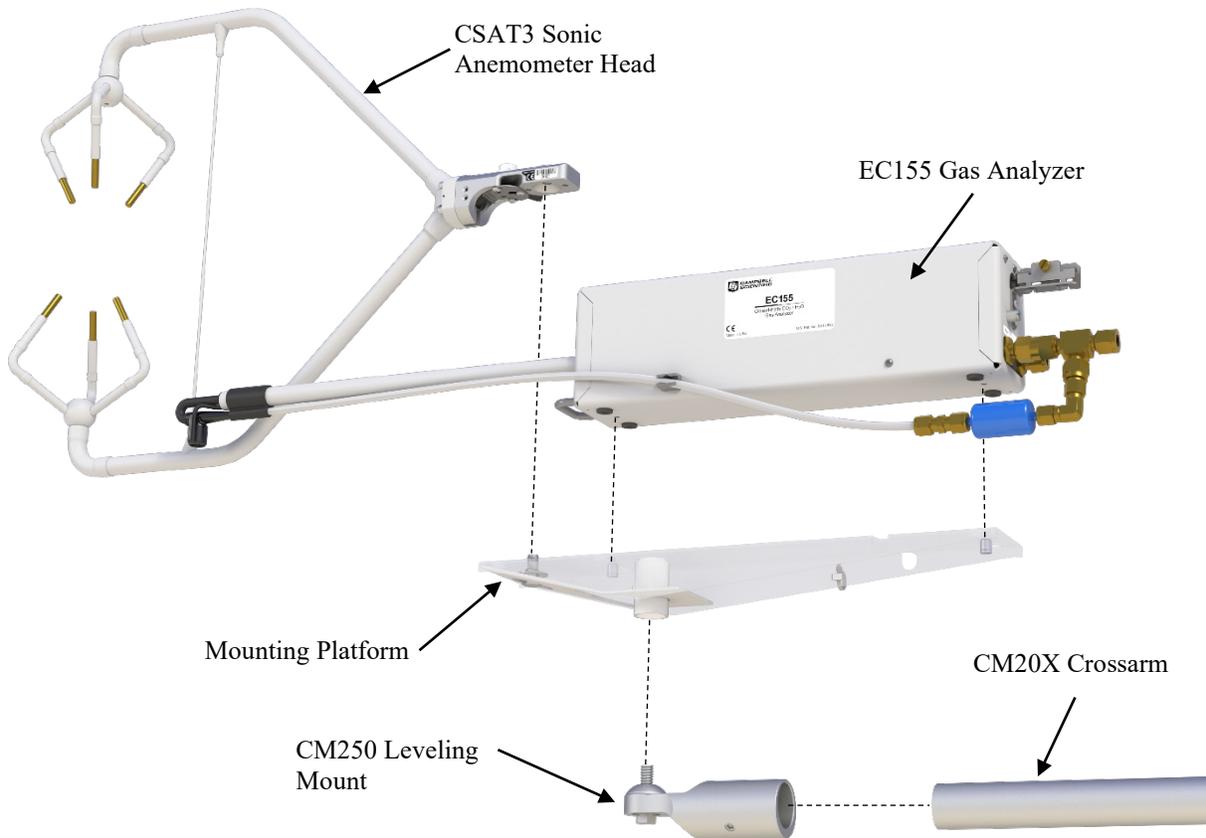


FIGURE 6-3. Exploded view of mounting newer design EC155 gas analyzer (EC155 sample cell serial numbers 2000 and greater) and CSAT3A sonic head (CSAT3A serial numbers 2000 and greater); cables not shown

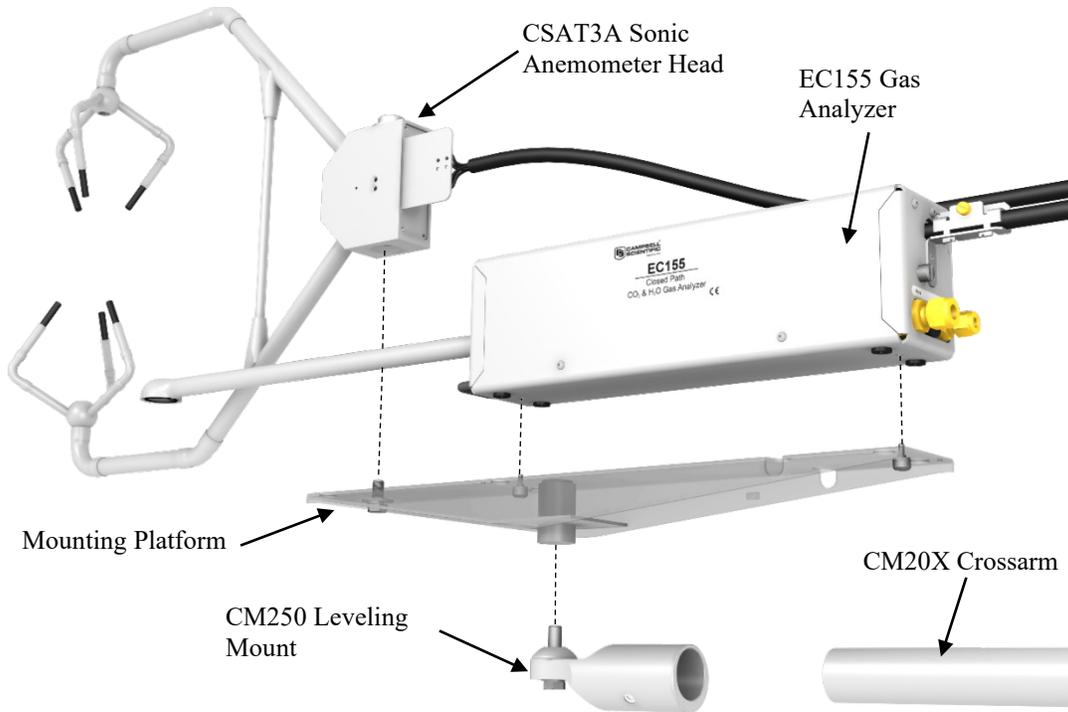


FIGURE 6-4. Exploded view of mounting older design EC155 gas analyzer (EC155 sample cell serial numbers less than 2000) and CSAT3A sonic head (CSAT3A serial numbers less than 2000).

NOTE

The CSAT3A sonic anemometer is similar to the CSAT3 and CSAT3B but has been designed specifically to work with the EC100 electronics and have optimum synchronization with the gas analyzer. It is possible for an existing CSAT3 to be upgraded to a CSAT3A. Contact Campbell Scientific for details.

7. Attach the EC100 electronic enclosure to the mast, tripod leg, or other suitable part of the mounting structure.

NOTE

The designed ingress protection rating of the EC100 is not intended for marine environments or other environments in which the enclosure may come in contact with corrosive chemicals (viculture or agriculture, for example), as components within the enclosure are at higher risk to exposure to these substances. However, instruments with EC100 enclosures are being used in these environments with additional precautions. If the instrumentation is intended for such an environment, contact Campbell Scientific for guidance before deploying the instrument.

- a. Attach the EC100 enclosure mounting bracket to the pipe by loosely tightening the u-bolts around the pipe. The u-bolts are found in the mesh pocket inside the EC100 enclosure. If the pipe does not run vertically up-and-down (for example, if you are attaching the enclosure to a leg of a tripod), rotate the bracket to the side of the pipe. As the enclosure must hang upright, angle adjustments may need

to be made by loosening the four nuts and rotating the bracket plates relative to one another. If the necessary angle cannot be reached in the given orientation, the four nuts may be removed and the top plate indexed by 90 degrees to allow the bracket to travel in the other direction (see FIGURE 6-5).

- b. Once adjusted, tighten all the nuts.
- c. Attach the EC100 enclosure to the bracket by loosening the bolts on the back of the enclosure, hanging the enclosure on the mounting bracket (it should slide into place and be able to securely hang from the bracket), and tightening the bolts (see FIGURE 6-6).

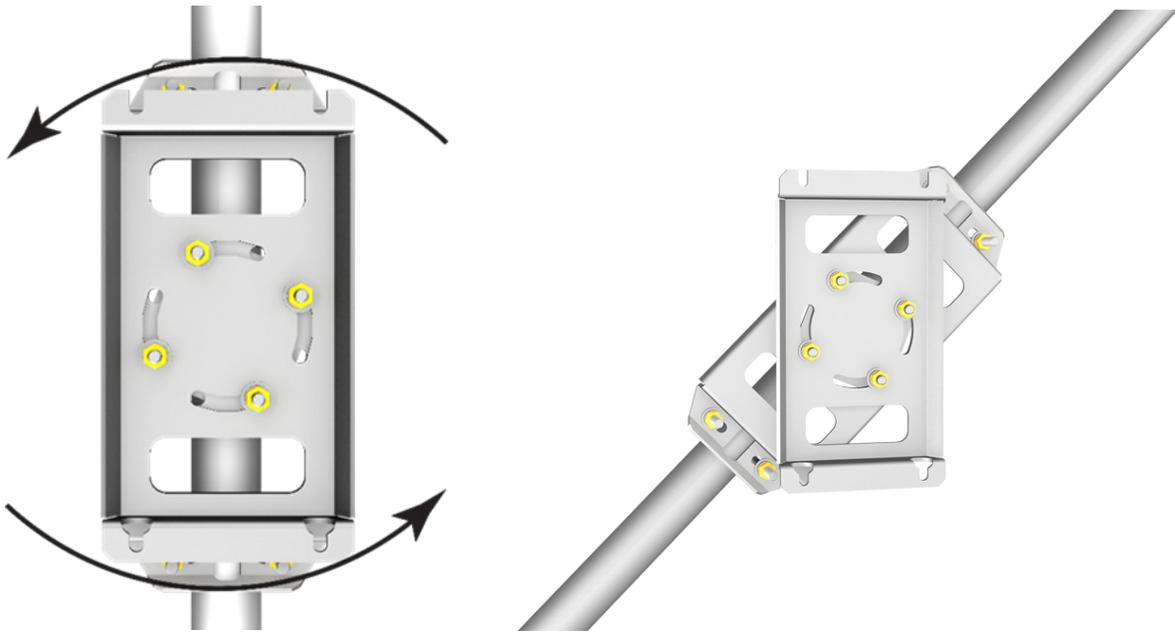


FIGURE 6-5. EC100 enclosure mounting bracket mounted on a vertical mast (left) and a tripod leg (right)

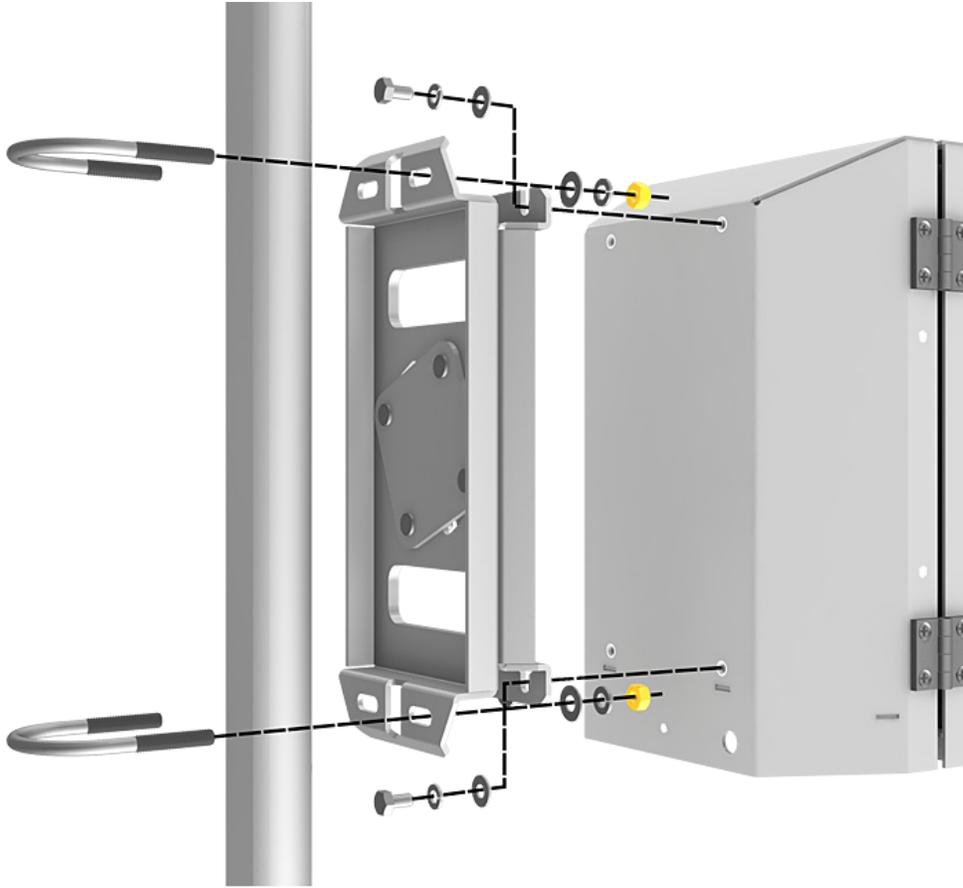


FIGURE 6-6. Exploded view of mounting the EC100 enclosure

8. Remove the EC100 enclosure desiccant from the plastic bag and put it back in the mesh pocket of the enclosure.
9. Adhere the humidity indicator card to the inside of the enclosure.

6.3 Plumbing

6.3.1 Flow

The EC155 has a small sample cell volume (5.9 cm³) to give good frequency response at a relatively low flow rate. The sample cell residence time is 59 ms for a sample flow of 6 LPM (assumes vortex bypass flow is 2 LPM, and total flow to the pump is a nominal 8 LPM). The CPEC200 pump module is designed to provide this flow for the EC155 but other user-supplied pumps may be used. There is no specific limitation to the flow rate that may be used with the EC155 but the sample cell pressure must be considered.

6.3.2 Pressure

The EC155 is designed to be used near ambient pressure, but it will not be damaged by operation under vacuum. The EC155 vortex sample cell includes an absolute pressure sensor to measure sample cell pressure, whereas the original EC155 sample cell included a differential pressure sensor to measure

the sample cell pressure relative to ambient pressure, which had a range of ± 7 kPa.

NOTE

If the original EC155 was operated less than 7 kPa from ambient pressure, the user was required to attach a separate, user-supplied pressure sensor. In either version of EC155 sample cell, the pressure of the sample cell is reported as a differential pressure in relation to ambient pressure.

For the sample cell with vortex intake, the pressure drop in the sample cell is approximately 6 to 8 kPa at a nominal 8 LPM pump flow (6 LPM flow to the sample cell and 2 LPM to the vortex bypass). This pressure drop will increase if the vortex bypass flow reduces; for example, when the bypass filter clogs. If the bypass flow is reduced for a significant time, the vortex will allow dust or other particles to travel to the sample cell, which eventually results in decreased signal strength. When the signal strength falls below 80%, the bypass filter should be replaced and the analyzer cleaned. See Section 9.2.1, *Vortex Filter Replacement and Vortex Intake Cleaning* (p. 35), for details.

For the older or original sample cell, the pressure drop in the heated intake assembly is approximately 2.5 kPa at 7 LPM flow with no filter. The inline filter adds approximately 1 kPa pressure drop when it is clean. This pressure drop will increase as the filter clogs. The filter should be replaced before the differential pressure reaches -7 kPa (unless the user has supplied a pressure sensor with a wider range). See Section 9.2.2, *Inline Intake Filter Replacement* (p. 39), for details on replacing the inline filter.

6.3.3 Filtration

Newer EC155 sample cells (serial numbers 2000 and greater) use vortex technology (U.S. Pat. No. 9,217,692) to separate particulates from the sample flow (see FIGURE 6-7), which eliminates the need for an inline filter.

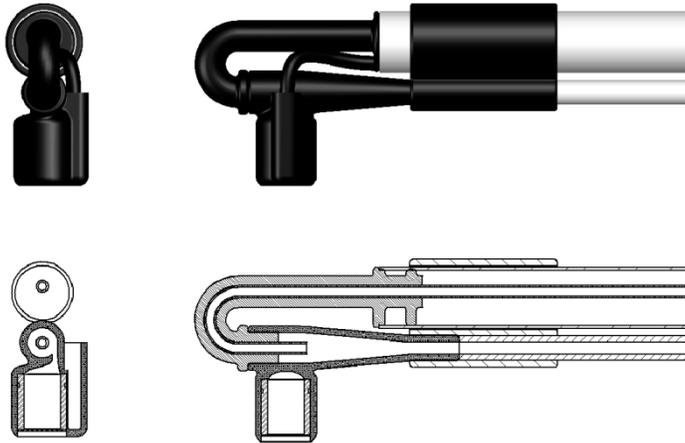


FIGURE 6-7. External views (top) and cross-sectional views (bottom) of the vortex intake.

The new intake works by spinning incoming air into a vortex, forcing particulates to the outside of the vortex, and out a bypass tube.

Sample air enters the larger-diameter side of the vortex chamber where the particles, which are denser than air, are spun to the outside of the vortex and gradually spiral towards the dirty air exit. Meanwhile, clean air is extracted from the vortex's center and sent to the gas analyzer's sample cell. See FIGURE 6-8 for an illustration of the vortex chamber's air flow. In FIGURE 6-8, warmer colors represent higher speeds of dirty air to the right (towards bypass), and cooler colors represent higher speeds of clean air to the left (towards sample cell).

This new intake dramatically increases the time between maintenance visits compared to intakes with traditional inline filters. Unlike traditional inline filters which degrade the frequency response, particularly of H₂O, as they become dirty, the vortex intake retains near-constant frequency response. A coarse screen (FIGURE 6-9) is used across the heated inlet to keep out large debris and insects. If the screen is found to collect excessive amounts of water droplets during rain or fog events or frost during very cold conditions, the screen may be easily removed using a metal pick.

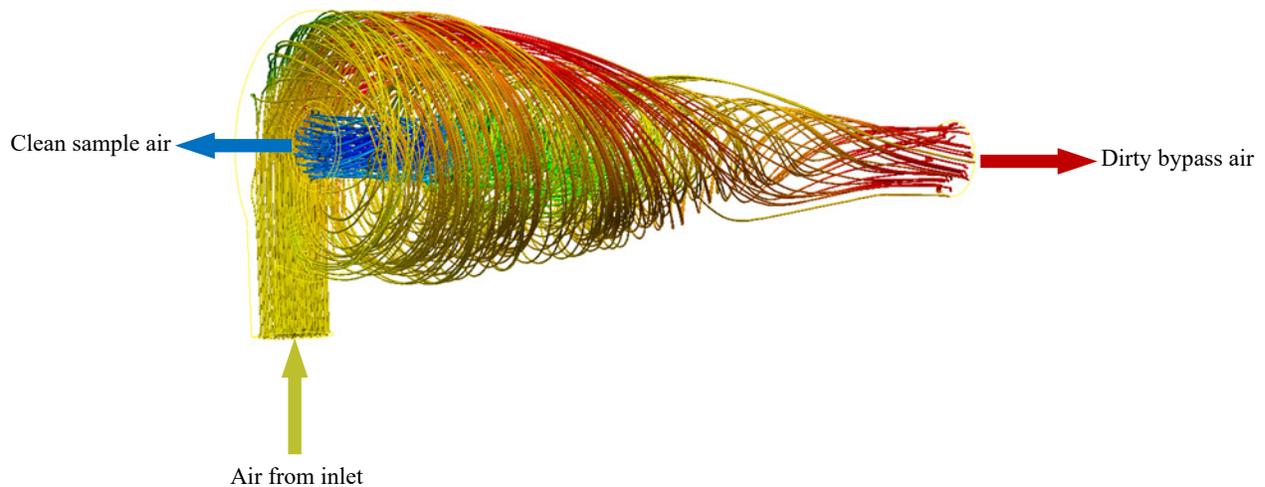


FIGURE 6-8. Cross-sectional view of vortex chamber and respective air flow



FIGURE 6-9. Screen located at underside of vortex intake

Older EC155 sample cells (serial numbers less than 2000) are typically operated with an inline filter element, although the analyzer will not be damaged by use without a filter. In either configuration, particulates will collect on the optical windows over time, reducing the signal levels until the windows must be cleaned (see Section 9.3, *Cleaning Analyzer Windows (p. 40)*). Using a filter on the inlet will increase the time before the windows must be cleaned. A finer pore size will keep the windows clean longer, but will need to be replaced more frequently. The previous-version intake assembly includes a 20 micron filter element, which gives a compromise between filter replacement and window cleaning.

6.3.4 Plumbing Connections

There are two connections to the EC155 sample cell: the **Zero/Span** inlet and **Pump** outlet, as illustrated in FIGURE 6-10. In the normal mode, a vacuum pump pulls an air sample from the sample intake through the sample cell, and in the case of the vortex intake, it also pulls bypass flow from the vortex. In *Zero-and-Span* mode the pump is turned off and a zero-and-span gas is pushed backwards through the sample cell, exhausted out through the sample inlet.



FIGURE 6-10. End view of EC155 analyzer showing ports for pump outlet (vortex bypass tubing and filter assembly not shown) and zero-and-span intake

6.3.4.1 Sample Intake

All new EC155 analyzers include a sample cell with vortex intake. Assembly of the vortex is described in Section 6.1, *Preparation of Vortex Intake (p. 11)*. Users with older analyzers may upgrade to the vortex intake by replacing their sample cell. Contact Campbell Scientific for more details.

It is possible to remove the intake from the sample cell following the instructions in Appendix C.2.1, *Detaching the Vortex Intake (p. c-1)*. This allows the intake to be replaced or cleaned, or a custom intake to be installed.

6.3.4.2 Pump

In normal mode, the EC155 uses a vacuum pump to pull an air sample through the sample cell and vortex bypass. See the discussion on flow and pressure in the previous section for pump requirements. The CPEC200 pump module is designed for use with the EC155. Connect the CPEC200 pump module or user-supplied sample pump to the 3/8-in Swagelok fitting at the back end of the vortex bypass tubing and filter assembly in line with the sample cell port labeled **Pump**.

6.3.4.3 Zero and Span

The zero-and-span inlet connects to the pump connection passage near the outlet of the sample cell. During normal operation the zero-and-span inlet should be plugged, either with a Swagelok 1/4-in plug, or with a tube connecting to a closed valve or manifold system such as the CPEC200 valve module. During zero and span, the zero or span gas can be pushed into this fitting to flow backward through the sample cell and exhausted through the intake assembly.

NOTE

The CPEC200 system includes a valve module controlled by a CR3000 datalogger, which automates the zero gas and CO₂ span gas flows during the zero-and-span procedure.

6.4 Wiring and Connections

FIGURE 6-11 and FIGURE 6-12 below show the EC100 electronics panel and the bottom of the EC100 enclosure, respectively. Refer to these figures during wiring and connecting.

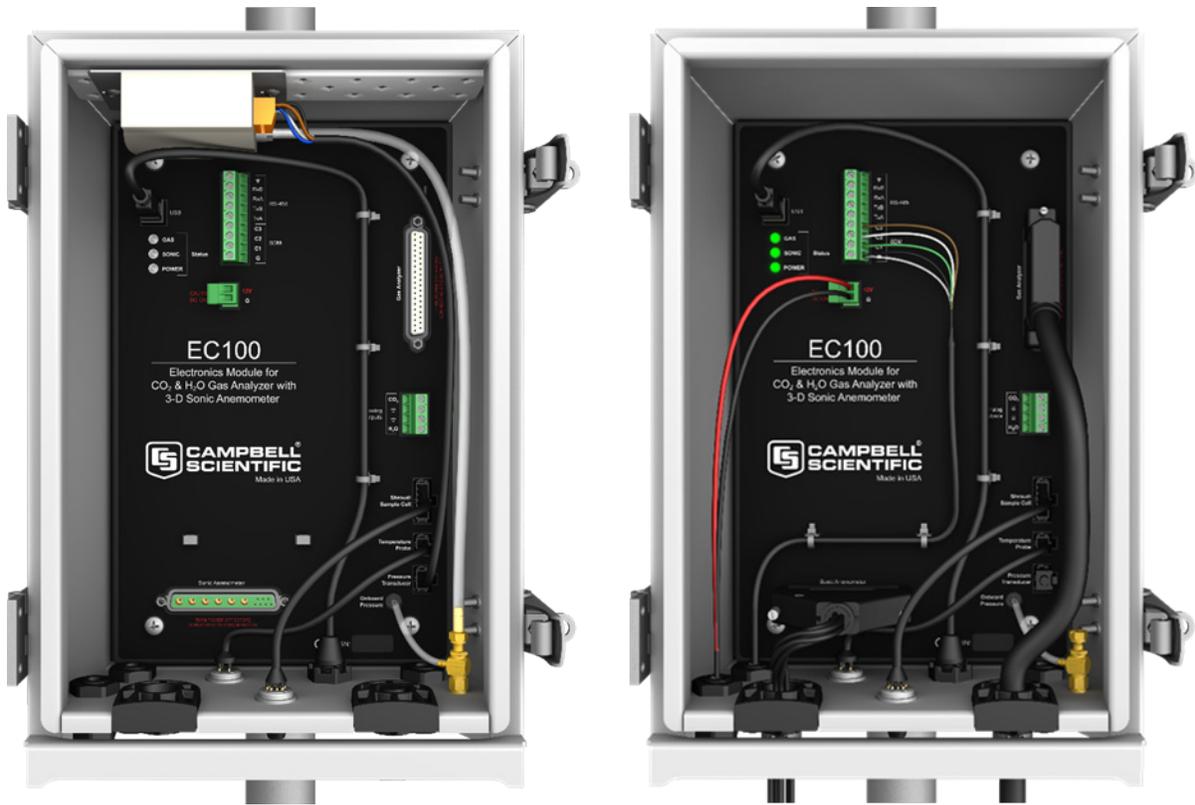


FIGURE 6-11. EC100 electronics front panel. The left figure shows the panel as it is shipped from the factory (enhanced barometer shown). The right figure shows the panel after the user has done all the wiring and made all connections (basic barometer used).

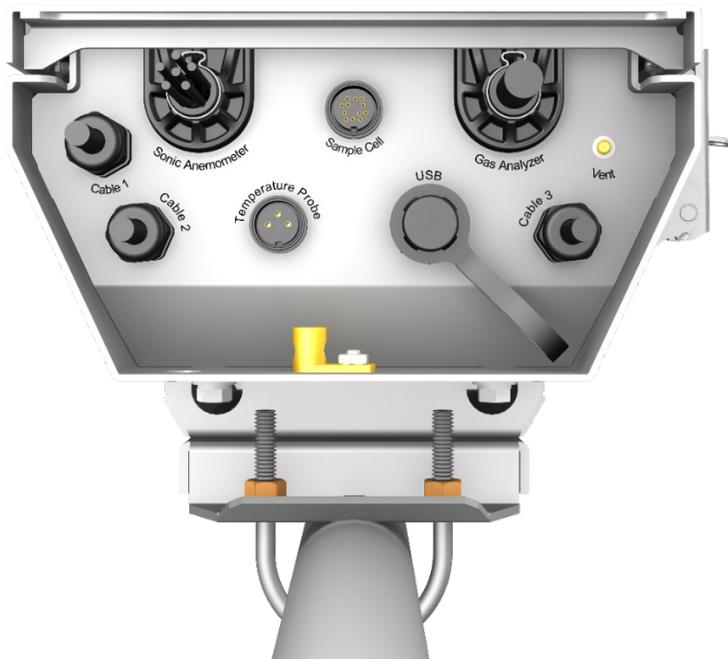


FIGURE 6-12. Bottom of EC100 enclosure

CAUTION

Do not connect or disconnect the EC155 gas analyzer head or CSAT3A sonic head while the EC100 is powered.

1. Connect the EC155 gas analyzer head. Begin by removing the black rubber cable entry plug on the bottom right of the EC100 enclosure. (This plug can be stored in the mesh pocket of the enclosure). Now insert the cable entry plug that is attached to the large cable of the EC155 gas analyzer head into the vacant slot. Push the connector at the end of the cable onto its mating connector (labeled **Gas Analyzer**) and tighten the thumbscrews (see FIGURE 6-12). The EC155 gas analyzer cable is approximately 3 m (9.8 ft) in length.
2. Connect the EC155 sample cell cable. Unscrew the sample cell connector cover, which is found on the bottom of the EC100 enclosure. Insert the 12-prong sample cell cable connector into the female connector on the enclosure and screw it firmly in place. The EC155 sample cell cable is approximately 3 m (9.8 ft) in length.
3. Connect the CSAT3A sonic head (skip this step if not using the CSAT3A). Similar to (a), begin by removing the black rubber cable entry plug found on the bottom left of the EC100 enclosure. Insert the cable entry plug on the CSAT3A cable into the slot and connect the male end to the female connector labeled **Sonic Anemometer** on the EC100 electronics (see FIGURE 6-13). Tighten the thumbscrews. The CSAT3A cable is approximately 3 m (9.8 ft) in length.



FIGURE 6-13. Connection for CSAT3A in EC100 module

NOTE Unlike the previous model CSAT3 3D sonic anemometer, the CSAT3A sonic head and the EC155 gas analyzer head have embedded calibration information; meaning that any CSAT3A and any EC155 may be used with any EC100.

4. Ground the EC100 by attaching a thick wire (for example, 12 AWG) to the grounding lug found on the bottom of the EC100 enclosure (see FIGURE 6-12). The other end of the wire should be connected to earth (chassis) ground (such as a grounding rod). For more details on grounding, see the grounding section of the CR3000 datalogger manual.

CAUTION Grounding the EC100 and other electrical components in the measurement system is critical. Proper grounding to earth (chassis) will ensure the maximum ESD (electrostatic discharge) protection and higher measurement accuracy.

5. Connect a communications signal cable to the EC100. Loosen the nut on one of the cable entry seals (Cable 1 or Cable 2) on the bottom of the EC100, remove the plastic plug (the plug can be stored in the mesh pocket in the enclosure), insert the cable, and retighten the nut by hand. Refer to the sections below on SDM, USB, RS-485, and analog communications for information on required signal cable types and connections to the EC100 panel.
 - a. **SDM Communications:** Use cable CABLE4CBL-L. “L” denotes the length of the cable, which is customer-specified at time of order. TABLE 6-1 below details which color of wire in the cable should be connected to each terminal found on the SDM connector of the EC100 panel.

EC100 Channel	Description	Color
SDM-C1	SDM Data	Green
SDM-C2	SDM Clock	White
SDM-C3	SDM Enable	Red (or brown)
G	Digital Ground	Black
G	Shield	Clear

- b. **USB Communications:** Use the EC100 USB cable to connect a PC to the USB port on the bottom of the EC100 enclosure.
- c. **RS-485 Communications:** Use cable CABLE3TP-L for lengths less than 152 m (500 ft). The connector on the EC100 panel labeled *RS-485* displays which terminals are for receiving and transmitting.
- d. **Analog Output:** Use CABLE4CBL-L or CABLE2TP-L. Once again, the customer specifies the length of this cable at time of order. The connector labeled **Analog Outputs** on the EC100 panel indicates where each wire should be connected (CO₂ voltage signal, H₂O voltage signal, and two ground connections).

6. Wire power and ground (power reference) cable CABLEPCBL-L to the EC100. Feed the cable through one of the cable port openings in the bottom of the EC100 enclosure and attach the ends into the green EC100 power connector. Plug the connector into the female power connector on the EC100 panel. Ensure that the power and ground ends are going to the appropriate terminals labeled **12V** and **ground**, respectively.
7. Connect the power cable to a power source. The power and ground ends may be wired to the **12V** and **G** ports, respectively, of a Campbell Scientific datalogger or to another 12 Vdc source.
8. Once power is applied to the EC100, three LED status lights on the EC100 panel will illuminate. The power LED will be green and the sonic and gas LEDs will be red until the unit has warmed up and is ready to make measurements at which time the LEDs will be green. If after several minutes the LED lights do not turn green, a diagnostic flag has been detected. Check the individual diagnostic bits to determine the specific fault. Diagnostics may be monitored using the Status window of *ECMon*, the user interface software included with the EC155 (see Section 7, *Settings* (p. 24)), or with a datalogger (see Section 10.2, *Datalogger Programming with CRBasic* (p. 50)). The diagnostics may reveal that the unit needs to be serviced (for example, clean the optical windows of the sample cell, clear the CSAT3A transducers of ice or debris, etc.).

7. Settings

Operation of the EC155 can be customized by changing the values of the settings. Factory defaults will work well for most applications, but the user may adjust the settings with a PC using either the *ECMon* software (see Section 7.3, *ECMon* (p. 28)) or the *Device Configuration Utility* (see Section 7.4, *Device Configuration Utility* (p. 31)), or with a datalogger using the **EC100Configure()** instruction (see Section 10.2, *EC100Configure()* *Instruction* (p. 53)).

7.1 Factory Defaults

TABLE 7-1 shows the name and default value for each of the settings.

TABLE 7-1. Factory Default Settings	
Bandwidth	20 Hz
SDM Address	1
Unprompted Output	Disabled
RS-485 Baud Rate	115200 bps
Unprompted Output Rate	10 Hz
Analog Output	Disabled
ECMon Update Rate	10 Hz
Sonic Transducer Shadow Correction	Disabled
Temperature Sensor	Auto-Detect (EC155 Sample Cell Thermistor or Thermocouple on older design)
Heater Manual Control	Enabled, 4.0 V (max)

EC100 Barometer	EC100 Basic or EC100 Enhanced (depending on order)
EC155 Sample Cell Pressure Sensor	Absolute (Differential for EC155 sample cell serial numbers less than 2000)
Differential Pressure	Auto-Detect (Enabled for EC155)

7.2 Details

This section gives an explanation for each setting.

7.2.1 Bandwidth

The EC100 has a user-selectable low-pass filter to select the bandwidth (5, 10, 12.5, or 20 Hz). Setting the bandwidth to a lower value will reduce noise. However, it must be set high enough to retain the high-frequency fluctuations in the CO₂ and H₂O mixing ratios, or the high frequency contributions to the flux will be lost. The factory default bandwidth of the EC100 is 20 Hz, which is sufficient for most flux applications. Lower bandwidth settings may be used for higher measurement heights, which inherently have lower frequency content. Refer to Appendix A, *Filter Bandwidth and Time Delay (p. A-1)*, for more information on the digital filter options.

If a spectral analysis is being done to evaluate the experimental setup, the bandwidth should be set to the Nyquist frequency, which is half the datalogger sample rate (for SDM output) or half the unprompted output rate (for USB and RS-485 output). This ensures that the data will not be under-sampled and that higher frequency variations will not be aliased to lower frequencies. Note that if too small a bandwidth is selected, high frequency fluxes may be under-measured.

7.2.2 SDM Address

This parameter must be set to use SDM output from the EC100. See Section 8.1, *SDM Output (p. 32)*, for details on using SDM output.

Each SDM device on the SDM bus must have a unique address. The EC155 has a factory default SDM address of 1, but may be changed to any integer value between 0 and 14. The value 15 is reserved as an SDM group trigger.

7.2.3 Unprompted Output

If the EC100 is to output data in one of the unprompted modes (USB or RS-485, see Section 8.2, *USB or RS-485 Output (p. 32)*), this setting must be set accordingly. The factory default is to disable the unprompted output, assuming data will be logged via SDM by a datalogger (see Section 8.1, *SDM Output (p. 32)*).

Only one unprompted output type (such as USB or RS-485) may be selected at a given time. The rate at which the EC100 outputs these data is determined by the *Unprompted Output Rate* setting.

7.2.4 Unprompted Output Rate

This setting determines the output rate for unprompted output (USB or RS-485, see Section 8.2, *USB or RS-485 Output* (p. 32)). If the unprompted output is disabled, this parameter is not used. The factory default output rate is 10 Hz, but it may be set to 10, 20, or 60 Hz.

7.2.5 RS-485 Baud Rate

If the unprompted output mode is set to RS-485, this parameter determines the baud rate. Otherwise this setting is not used. The RS-485 baud rate defaults to 115200 bps, although the user may enter another value.

7.2.6 Analog Output

The EC100 has two analog outputs for CO₂ and H₂O molar mixing ratios (see Section 8.3, *Analog Outputs* (p. 34), for more information). These outputs may be enabled or disabled with this setting. The default is for analog output to be disabled.

7.2.7 ECMon Update Rate

This setting determines the rate at which data are sent over the USB connection to the PC while running *ECMon*. The default setting of 10 Hz should be adequate in most situations.

7.2.8 Sonic Transducer Shadow Correction

The CSAT3, CSAT3A, and CSAT3B suffer minimal wind distortion compared to many other sonic anemometer designs thanks to the very low ratio of transducer diameter to sonic path length and since the non-orthogonal geometry keeps the sonic paths at angles closer to perpendicular with respect to a mean horizontal wind flow. However, there are cases, such as when oncoming wind has high angles of attach (for example, low frequency eddies at on a tall tower), that will lead to more shadowing. Accordingly, an **optional** wind shadow correction specific to the CSAT3-series transducer diameter and sonic path length has been implemented in EC100 OS versions 6.0 and newer.

NOTE

For this setting to be viewed and enabled, *ECMon* version 1.6 or newer or *Device Configuration Utility* version 2.12 or newer must be used.

This shadow correction, known as the Kaimal correction (Kaimal, 1979ⁱ and Horst et al, 2015ⁱⁱ), is applied according to:

$$U_{i_{measured}} = U_i (0.84 + 0.16 \sin(\theta_i))$$

ⁱ Kaimal, J.C. (1979) Sonic anemometer measurement of atmospheric turbulence. Proceeding of the Dynamic Flow Conference, Skovlunde. DISA Electronic A/S, pp 551 – 565.

ⁱⁱ Horst, (2015) Correction of a Non-orthogonal, Three-Component Sonic Anemometer for Flow Distortion by Transducer Shadowing. *Boundary-Layer Meteorol* **155**: 371 – 395. DOI 10.1007/s10546-015-0010-3.

Where:

U_i = the magnitude of the wind vector parallel to the sonic path without shadowing errors

i = a placeholder index for a , b , or c , representing the three sonic paths, and

θ_i = the angle between the three-dimensional wind vector and the a -, b -, or c -sonic path (see FIGURE 7-1)

The EC100 embedded code improves the estimates of θ – and therefore the accuracy of the correction – by iteratively applying the above correction three times for each measurement of each sonic path. Since there continues to be some debate on the appropriateness of this and other shadow corrections in turbulent versus laminar flows, the default of this setting is **Disabled**.

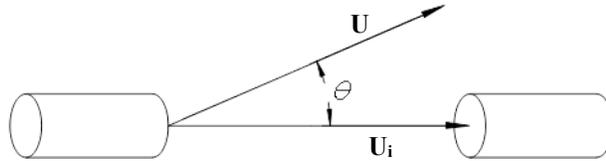


FIGURE 7-1. Angle θ is defined as the angle between the three-dimensional wind vector, \mathbf{U} , and the vector component parallel to the sonic path, \mathbf{U}_i

7.2.9 Temperature Sensor

The EC155 measures the temperature of the sample-cell block with a thermistor (or thermocouple for older units) embedded in the block. With the **Auto-Select** default setting, the EC100 will automatically detect that an EC155 is connected to the electronics and will report temperature measurements from the sample cell.

To diagnose problems with the temperature measurement, a fixed temperature value may be used, or the temperature sensor may be selected manually.

7.2.10 Fixed Temperature Value

If the **Temperature Sensor** setting is **None**, the EC155 will use the value of this setting for the sample-cell temperature. This mode is intended for troubleshooting only. In normal operation, the **Temperature Sensor** is set to **Auto-Select** and this setting is not used.

7.2.11 Heater Manual Control

This setting turns on the intake heater, which heats the sample air to prevent condensation in the intake tube and sample cell. On the newer design EC155 with vortex intake, all of the heat is applied at the inlet of the vortex, which additionally helps to keep the inlet free from dew or frost. In the case of fog, the heated inlet also aids in evaporating suspended water droplets in the sample air stream. The default value of this setting is enabled with the maximum voltage of 4.0 V applied. This will heat the sample air on the order of a few degrees and will consume approximately 0.8 W of power.

7.2.12 EC100 Barometer

This setting determines which pressure sensor will be used to measure the barometric pressure. The EC100 always includes the EC100 basic barometer, but it may be ordered with the optional EC100 enhanced barometer. This setting is factory defaulted to the enhanced barometer if ordered and to the basic barometer otherwise.

There are two other possible values for this setting. First, the user may provide a barometric pressure sensor. In this case, the setting should be changed to **User Supplied**, with the appropriate values for gain and offset entered (see below). The final option is to select **None**. The EC100 will use a fixed (see below) value for pressure. This mode is intended for troubleshooting only.

7.2.12.1 Pressure Gain

If the **Pressure Sensor** is set to **User Supplied**, this setting gives the gain factor (kPa/V) used to convert measured voltage to pressure. Normally the **Pressure Sensor** is set to **EC100 Basic** or **EC100 Enhanced**, and this setting is not used.

7.2.12.2 Pressure Offset

If the **Pressure Sensor** is set to **User Supplied**, this setting gives the offset (kPa) used to convert measured voltage to pressure. Normally the **Pressure Sensor** is set to **EC100 Basic** or **EC100 Enhanced**, and this setting is not used.

7.2.12.3 Fixed Pressure Value

If the **EC100 Barometer** setting is **None**, the EC155 will use the value of this setting for the barometric pressure. This mode is intended for troubleshooting only. In normal operation this setting is not used.

7.2.13 EC155 Sample Cell Pressure Sensor

This setting should be set to **Absolute** if a newer EC155 sample cell (serial number 2000 or greater) is used. For older EC155 sample cells (serial numbers less than 2000), set this to **Differential**.

7.2.14 Differential Pressure

This setting should be set to **Auto-Select**, regardless of the version of sample cell being used. Disabling this setting will result in the ambient pressure measured by the EC100 barometric pressure sensor being used as the sample cell pressure. Because this setting should not be altered for the vast majority of applications, it is not shown in *ECMon* but it can be accessed using *Device Configuration Utility*.

7.3 *ECMon*

Settings for the EC155 are easily verified and/or changed by using the Windows PC support software *ECMon* (short for Eddy Covariance Monitor), which is found at www.campbellsci.com/downloads. The settings associated with the newer version of the sample cell (EC155 sample cell serial numbers 2000 and greater) and the sonic transducer shadow correction require that version 1.6 or newer of *ECMon* be used.

NOTE

For the newer version of the EC155 with vortex intake (sample cells with serial number 2000 and greater), use *ECMon* version 1.6 or newer.

Before connecting the EC100 to the computer, install the USB driver through *Device Configuration Utility* (available at www.campbellsci.com/downloads). Select the EC100 device type, and click **Install USB Driver**.

Once the driver is installed, download and run the *ECMon.exe* install file. Launch *ECMon*, and connect the EC100 electronics to the PC with the included EC100 USB cable. The USB connection for the EC100 electronics is found on the bottom of the enclosure (see FIGURE 6-12). Once connected, select the appropriate communications port in the *ECMon* main page and click **Connect**. Next, click on the **Setup** button (see FIGURE 7-2). All of the above settings are now available for the user to change (see FIGURE 7-3).

Besides changing settings, *ECMon* is also a useful tool for other common tasks such as:

- Monitoring real-time data from the EC155 using the Display window.
- Performing a manual zero and span of the instrument (see Section 9.4, *Zero and Span* (p. 43)).
- Troubleshooting and monitoring diagnostics using the Status window (see FIGURE 7-4).

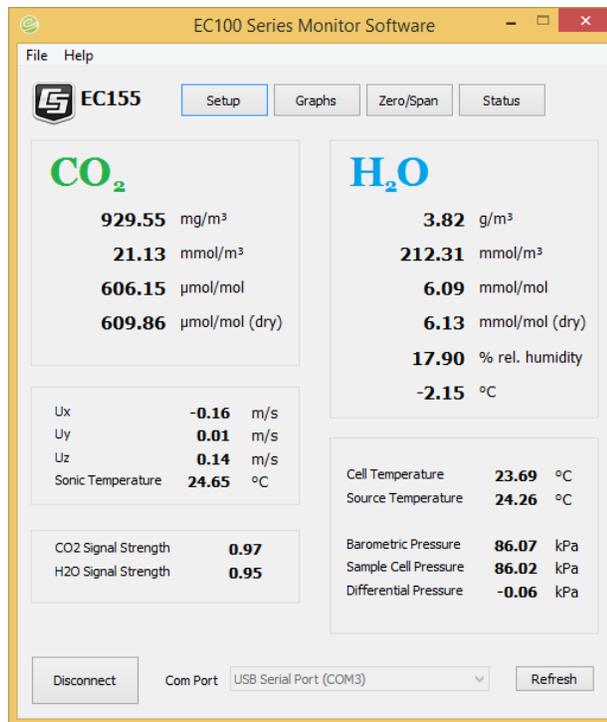


FIGURE 7-2. Main window of *ECMon*

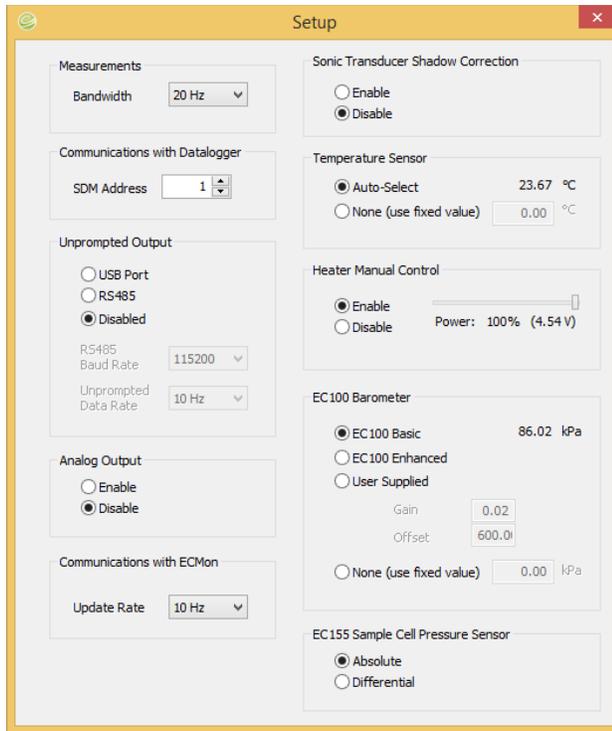


FIGURE 7-3. Setup window in EComon. Note that a few of the most rarely used settings have been omitted in Setup window of EComon for convenience. To access all settings, use Device Configuration Utility.

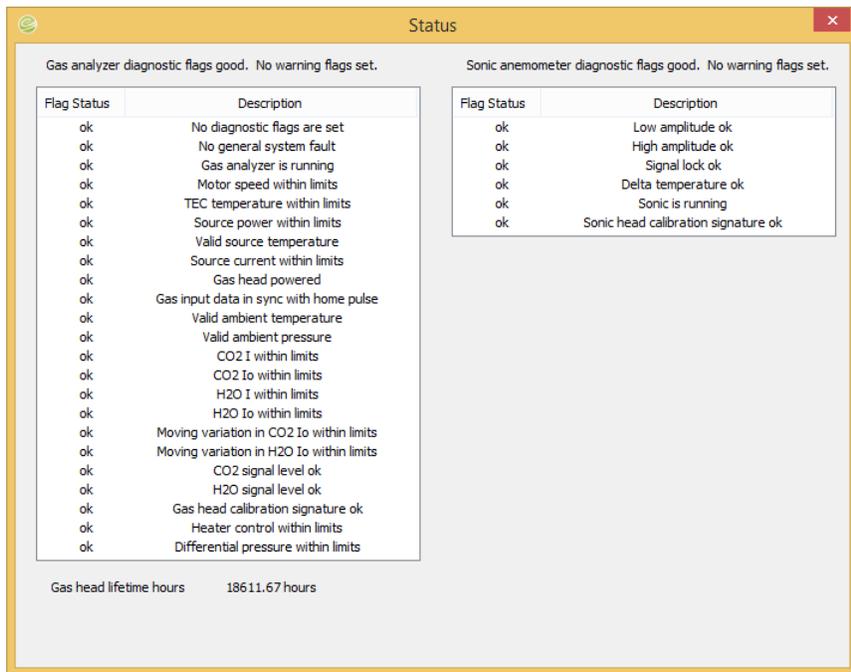


FIGURE 7-4. EComon Status window

7.4 Device Configuration Utility

The *Device Configuration Utility* software may also be used to change settings, although *ECMon* is generally preferred because of the more user-friendly interface. *Device Configuration Utility* may be downloaded at www.campbellsci.com/downloads.

The settings associated with the newer version of the sample cell (EC155 sample cell serial numbers 2000 and greater) and the sonic transducer shadow correction require that version 2.12 or newer of *Device Configuration Utility* be used.

After launching the *Device Configuration Utility*, select **EC100** from the list of device types. If this is the first time connecting it to the computer, click **Install USB Driver** and follow the onscreen instructions to install the driver before connecting with the USB cable. Then, with the EC100 connected to the computer, select the correct USB communication port, and click **Connect**. Once connected, the **Settings** tab displays all current settings. Click **Apply** to save any changes.

Device Configuration Utility is also used to send an updated operating system to the EC100 electronics. The **Send OS** tab gives directions on this procedure.

NOTE

The newer design EC155 sample cell (serial numbers 2000 and greater) requires *Device Configuration Utility* version 2.12 or newer and EC100 operating system version 6.0 or newer. The setting for applying a sonic transducer shadow correction requires EC100 operating system version 6.0 or newer.

8. EC100 Outputs

The EC100 outputs data in one of four types: SDM, USB, RS-485, or analog. In general, Campbell Scientific, Inc. recommends that SDM be used if a Campbell Scientific datalogger is responsible for data collection. However, RS-485 output is recommended over SDM if cable lengths exceed 100 meters (about 320 ft).

If a PC is being used for data collection, USB and RS-485 are suitable outputs. Analog output may also be used, however, only CO₂ mixing ratio and H₂O mixing ratio will be output. More information regarding each output type is provided in the sections below.

NOTE

The EC100 synchronously samples the gas in the EC155 sample cell and the CSAT3A sonic head. However, a delay induced by the intake assembly must be accounted for to ensure maximum covariance. The exact delay will depend on the length and size of the intake tubing and the pump flow rate. See Appendix A, *Filter Bandwidth and Time Delay* (p. A-1), or the CPEC200 manual for details.

8.1 SDM Output

SDM (Synchronous Device for Measurement) is a Campbell Scientific communication protocol that allows synchronized measurement and rapid communication between a Campbell Scientific datalogger and multiple devices including the EC155. Although nearly all of the Campbell Scientific dataloggers support SDM, only the CR6, CR1000X, CR1000, CR3000, and CR5000 dataloggers support the EC155.

To use SDM data output, connect an SDM cable from the EC100 (see Section 6.4, *Wiring and Connections* (p. 20)) to a CR6, CR1000X, CR1000, CR3000, or CR5000 datalogger. On CR1000 dataloggers, the SDM port is made of terminals C1 – C3. The default SDM port for CR6 and CR1000X dataloggers is made of terminals C1 – C3, though it can be changed with the **SDMBeginPort()** instruction. On CR3000 and CR5000 dataloggers, the SDM protocol uses SDM-dedicated ports SDM-C1, SDM-C2, and SDM-C3.

Each SDM device on the SDM bus must have a unique address. The EC155 has a factory default SDM address of 1, but may be changed to any integer value between 0 and 14 (see Section 7.2.2, *SDM Address* (p. 25)).

The sample rate for SDM output is determined by the inverse of the datalogger scan interval, as set by the user in the datalogger program. Data are output from the EC100 when a request is received from the logger, i.e. a *prompted* output mode. The number of data values sent from the EC100 to the datalogger is also set by the user in the datalogger program. CRBasic, the programming language used by Campbell Scientific dataloggers, uses the **EC100()** instruction to get data from an EC155. This instruction is explained in detail under Section 10.2, *Datalogger Programming with CRBasic* (p. 50), of this manual.

8.2 USB or RS-485 Output

In contrast to the SDM output mode, which is prompted by a datalogger, data can also be output from the EC100 via USB or RS485 in an unprompted mode. In this case the EC100 sends out data without initiation from the receiving device, at a rate determined by the EC100. Only one unprompted output type (i.e., USB, RS-485) may be selected at a given time. RS-485 output is recommended over SDM if cable lengths exceed 100 meters. If a Campbell Scientific datalogger is not being used to collect the data from the EC155, either unprompted mode is recommended.

To use USB or RS-485 output, connect a USB or RS-485 cable from the EC100 to the receiving device (see Section 6.4, *Wiring and Connections* (p. 20)), and configure the settings (see Section 7, *Settings* (p. 24)).

The *Unprompted Output* parameter must be set to USB or RS-485.

If RS-485 is selected, the *RS-485 Baud Rate* must be set.

The *Unprompted Output Rate* must be set to the desired output rate.

All output data will be in ASCII format, with each data element separated by a comma. To view the data in terminal mode, in *Device Configuration Utility* choose **Unknown** as the device type and enter **Connect**. Each record will terminate with a carriage return and line feed. TABLE 8-1 below lists the

elements in each output array, and FIGURE 8-1 shows an example USB data feed in terminal mode.

Data Element	Description	Units/comments
1	Ux	m/s
2	Uy	m/s
3	Uz	m/s
4	Sonic temperature	°C
5	Sonic diagnostic flag	
6	CO ₂ density	μmol CO ₂ /mol
7	H ₂ O density	mmol H ₂ O/mol
8	Gas diagnostic flag	
9	Sample-cell temperature	°C
10	Sample-cell pressure	kPa
11	CO ₂ signal strength	Nominally 0.0 to 1.0
12	H ₂ O signal strength	Nominally 0.0 to 1.0
13	Pressure differential ^{1/} (used for EC155 only, disregard for IRGASON/EC150)	kPa
14	Source housing temperature (only applicable for EC150 and IRGASON, the EC155 does not have a thermistor in the detector housing)	°C
15	Detector housing temperature	°C
16	Counter	Arbitrary
17	Signature	Arbitrary in hexadecimal

^{1/}The newer design EC155 sample cell (serial numbers 2000 and greater) uses an absolute pressure sensor to measure sample cell pressure, but the pressure differential relative to ambient pressure is reported. This provides consistency with the older design outputs and is useful in monitoring potential flow constrictions in the intake.

```
Terminal
-0.05097,-1.15870,0.37277,12.66450,0,423.592,13.200,0,12.426,81.633,0.971,0.965,-5.856,13.522,-96.705,626,4a6a
-0.08351,-0.98278,0.43968,12.62096,0,423.773,13.239,0,12.427,81.632,0.971,0.965,-5.855,13.522,-96.814,627,ce13
-0.05419,-0.99298,0.31760,12.64642,0,423.428,13.256,0,12.427,81.631,0.971,0.965,-5.856,13.522,-96.823,628,02ec
-0.00363,-0.98847,0.25852,12.66149,0,423.341,13.238,0,12.427,81.634,0.971,0.965,-5.853,13.522,-96.730,629,730e
0.00173,-1.08329,0.26076,12.62479,0,423.465,13.229,0,12.427,81.636,0.971,0.965,-5.851,13.522,-96.746,630,5e3b
0.03663,-1.10480,0.13558,12.36319,0,423.259,13.228,0,12.427,81.636,0.971,0.965,-5.851,13.522,-96.564,631,b3bc
0.09997,-1.14926,0.18538,12.36399,0,422.762,13.178,0,12.427,81.633,0.971,0.965,-5.855,13.522,-96.831,632,409e
```

FIGURE 8-1. An example of USB data output in terminal mode

The final data element in each row or output array is the signature, a four character hexadecimal value that is a function of the specific sequence and number of bytes in the output array. The recording device (such as a PC or datalogger) calculates its own signature using each transmitted byte until encountering the transmitted signature. The computed signature and the transmitted signature are compared. If they match, the data were received correctly. This is very similar to a Cyclic-Redundancy-Check (CRC).

In most situations, a PC begins by reading in the ASCII data and extracting the last four ASCII characters, casting them as Long data type. The signature is then calculated on the science data sent from the EC155, starting with CO₂ and ending on the counter. All the characters after the counter are not part of the signature. Once the signature is computed using the algorithm below, it is compared to the transmitted signature. If signatures do not match, the data should be disregarded.

The following block of code is an example implementation of Campbell Scientific's signature algorithm in the programming language C. To generate the signature of an output array of bytes, the *seed* needs to be initialized to 0xaaaa and a pointer passed to the first byte of the output array. The number of bytes in the output array should be entered in as the *swath*. The returned value is the computed signature.

```
//signature(), signature algorithm.
// Standard signature is initialized with a seed of 0xaaaa.
// Returns signature.
unsigned short signature( unsigned char* buf, int swath,
unsigned short seed ) {
unsigned char msb, lsb;
unsigned char b;
int i;
msb = seed >> 8;
lsb = seed;
for( i = 0; i < swath; i++ ) {
b = (lsb << 1) + msb + *buf++;
if( lsb & 0x80 ) b++;
msb = lsb;
lsb = b;
}
return (unsigned short)((msb << 8) + lsb);
}
```

8.3 Analog Outputs

If analog output is enabled, the EC100 will output two analog signals that correspond to CO₂ and H₂O molar mixing ratios. The signals range from 0 to 5 V. TABLE 8-2 below, gives the multipliers and offsets for the analog outputs.

TABLE 8-2. Multipliers and Offsets for Analog Outputs

Mixing Ratio	Voltage Output Multiplier	Offset
CO ₂ (μmol CO ₂ ·mol ⁻¹)	211.27 (μmol CO ₂ ·mol ⁻¹ V ⁻¹)	-56.34 (μmol CO ₂ ·mol ⁻¹)
H ₂ O (mmol H ₂ O·mol ⁻¹)	11.31 (μmol H ₂ O·mol ⁻¹ V ⁻¹)	-3.04 (mmol H ₂ O·mol ⁻¹)

9. Maintenance

There are five basic types of maintenance for the EC155/EC100: intake cleaning and filter replacement (vortex bypass filter for newer EC155 sample cells or inline filter for older EC155 sample cells), analyzer cleaning, zero and spanning, replacing analyzer desiccant/scrubber bottles, and factory recalibration.

9.1 Routine Maintenance

The following items should be examined periodically:

- Check the humidity indicator card in the EC100 enclosure. If the highest dot has turned pink, replace or recharge the desiccant bags. Replacement desiccant bags may be purchased, or old ones may be recharged by heating in an oven. See the manual ENC10/12, ENC12/14, ENC14/16, ENC16/18, available at www.campbellsci.com, for more details on recharging desiccant bags.
- Make sure the Power and Gas LED status lights on the EC100 panel are green. If not, verify that all sensors are connected securely and that the instruments are powered. Also check the individual diagnostic bits for the specific fault. See TABLE 10-2 and TABLE 10-3.

Usually, the CSAT3A sonic anemometer calibration remains valid unless a transducer fails or damage to the instrument leads to a change in geometry. The sonic anemometer requires calibration when:

- It develops a wind offset greater than the specification
- It sets diagnostic flags under dry conditions with little to no wind and with no obstruction in the ultrasonic paths

The wind offset is tested by creating a zero-wind environment. This is best done in a laboratory setting with HVAC vents closed or covered to reduce air currents and by encircling the mounted sensor with a large plastic bag (for example, an unused refuse bag). Use caution not to block the sonic paths. Once the CSAT3A is connected to an EC100 and powered on, wind offsets may be viewed by connecting the EC100 to a computer and using *ECMon* to graph u_x , u_y , and u_z wind components (see Section 7.3, *ECMon* (p. 28)). In this zero-wind environment, u_x and u_y should be less than $\pm 8 \text{ cm}\cdot\text{s}^{-1}$ ($\pm 0.08 \text{ m}\cdot\text{s}^{-1}$) and u_z should be less than $\pm 4 \text{ cm}\cdot\text{s}^{-1}$ ($\pm 0.04 \text{ m}\cdot\text{s}^{-1}$). If recalibration is deemed necessary, contact Campbell Scientific.

9.2 Intake Cleaning and Filter Replacement

This section has been divided into two parts, 9.2.1 and 9.2.2. Section 9.2.1 applies to the newer design EC155 sample cell with vortex intake. Section 9.2.2 applies to the older design EC155 sample cell without vortex intake (sample cell serial numbers less than 2000).

9.2.1 Vortex Filter Replacement and Vortex Intake Cleaning

The vortex intake is able to separate particulates from the sample air as long as there is adequate flow through the vortex's bypass tube and filter. With a clean bypass filter and a nominal total flow setting of 8 LPM, approximately 2 LPM

flow gets directed to the bypass, 6 LPM flow goes to the sample cell, and the differential pressure output reads between -8 and -6 kPa. As the filter becomes clogged (typically, this takes many months), the bypass flow will be reduced, which will lead to a lower differential pressure since the pump must work harder to maintain the same total flow. Also, the sample air will begin to carry more particulates that can build up in the sample cell, causing the CO₂ and H₂O signal strengths to decrease. When either signal strength falls below 0.8, the following maintenance should be performed:

- Replace vortex filter
- Clean bypass tubing and vortex chamber
- Clean analyzer windows and internal sample cell

The sections below provide instructions on performing these maintenance items, except for cleaning the analyzer windows and internal sample cell, which is covered in Section 9.3, *Cleaning Analyzer Windows* (p. 40).

9.2.1.1 Replace Vortex Filter

Follow these steps to replace the vortex filter.

1. Power down the pump and allow a moment for pressure to equilibrate inside the analyzer.
2. Loosen the 1/4-in Swagelok nuts that secure the blue bypass filter in place. Remove and discard the used filter assembly and install a new filter assembly.

CAUTION

Do not over-tighten the Swagelok nuts, as this could introduce leaks. For more information on tightening Swagelok fittings, see Appendix H, Swagelok Fittings, in the AP200 CO₂/H₂O Atmospheric Profile System manual available at <https://s.campbellsci.com/documents/us/manuals/ap200.pdf>.

NOTE

The filter assembly comes with new 1/4 inch Swagelok nuts and is shown in FIGURE 9-1. It may be ordered from Campbell Scientific. Users could also provide their own filters, but the pore size should be small enough to keep particulates from reaching the pump (for example, 25 μ m).



FIGURE 9-1. The vortex filter assembly includes a 25 μ m particulate filter with 1/4-in Swagelok nuts on either side.

9.2.1.2 Cleaning the Bypass Tubing and Vortex Chamber

To clean the bypass tubing and vortex chamber follow the steps below.

1. Pull the bypass tube out of the bypass tube sleeve (see FIGURE 9-2). If the tube is visibly dirty, remove the section of tubing by loosening the 1/4-in Swagelok nut on the other end. Shake the tube out, or if needed, flush it out with a solvent such as water or a water-isopropyl alcohol solution. The tubing can also be replaced with 63.5 cm (2.1 ft) length of high-density polyethylene tubing of 1/4-in outer diameter and 1/8-in inner diameter.
2. Once clean, reattach the tubing to the vortex filter fittings. Be sure not to over tighten the Swagelok nut.

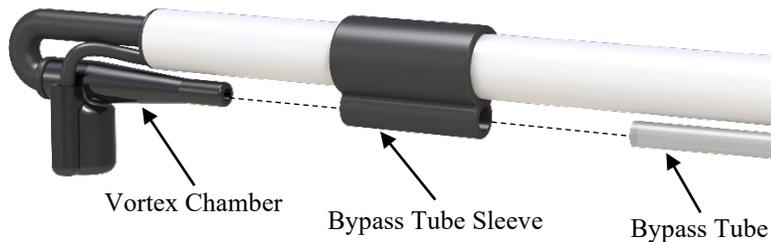


FIGURE 9-2. Exploded image of vortex intake with bypass tube pulled from bypass tube sleeve, and bypass tube sleeve pulled back away from vortex chamber

3. Slide the bypass tubing sleeve about 3 cm (1.2 in) along the intake towards the sample cell until there is enough space to pull the base of the vortex chamber out of the sleeve. Refer again to FIGURE 9-2.
4. Pull the vortex chamber slightly backwards towards the sample cell in order to free it from the intake end piece. Refer to FIGURE 9-3.

CAUTION

Be careful not to stretch the vortex inlet heater cable by pulling the vortex chamber too far from the intake.

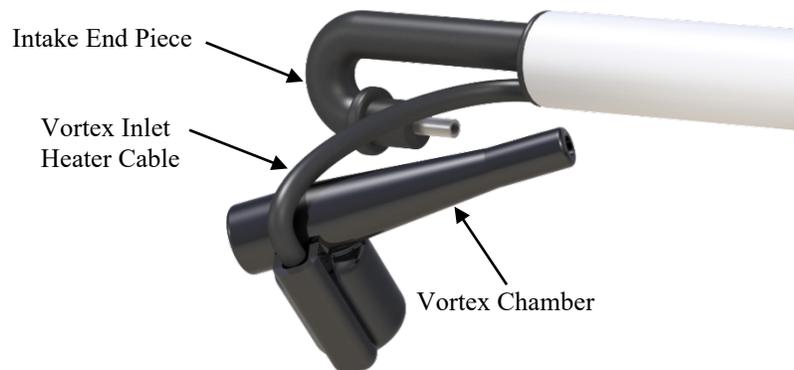


FIGURE 9-3. Pulling gently backwards on the vortex chamber will release it from the intake end piece. The vortex inlet heater cable remains attached.

5. Now with the vortex chamber open on both sides, use a rolled up piece of damp cloth or damp paper towel to floss back and forth through the vortex chamber. If the chamber has been contaminated with organic particulates, the cloth or paper towel may be dampened with isopropyl alcohol. Make sure to floss at various angles to ensure all internal surfaces are wiped clean. See FIGURE 9-4.

CAUTION

Do not use anything abrasive to clean out the vortex chamber, as scratching the internal surface may lead to decreased performance of the vortex.



FIGURE 9-4. A damp paper towel or cloth used to floss and clean inside surfaces of vortex chamber

6. To clean out the intake sample tubing, turn on the pump and plug the ends of the intake sample tubing (the small stainless steel tube) and the bypass tubing with fingers. After approximately one minute, when a relatively strong vacuum has developed, quickly release the end of the intake sample tubing. The burst of air flowing through the tube will help clear out any debris into the sample cell.
7. Repeat this step until the windows no longer become dirtier (CO₂ and H₂O signal levels do not change), indicating that no more dust is being removed from the intake sample tube. When finished, turn off the pump. If this procedure does not adequately clean the intake tubing, the intake assembly may be detached and flushed out with air or a solvent such as water or a water-alcohol solution. See Appendix C.2, *Cleaning Intake Tube (p. C-1)*, for details on detaching the intake and cleaning it.

NOTE

During this step, ambient air will rush in and blow dust from the inner walls of the intake tube, which is likely to be deposited on the analyzer windows. For this reason, Campbell Scientific recommends performing the dust blowout prior to cleaning windows.

8. Reassemble the vortex intake. The gas analyzer windows and sample cell are now ready to be cleaned as detailed in Section 9.3, *Cleaning Analyzer Windows* (p. 40).

9.2.2 Inline Intake Filter Replacement

This section only applies for users with EC155 models with serial numbers less than 2000.

The differential pressure between the sample cell and ambient pressure should be monitored over time in the output data. (This can also be done using the display screen of *ECMon*).

If the differential pressure approaches the limit of the full scale range (-7 kPa), it is likely that the intake filter is clogged and should be replaced. To replace the filter, follow these steps:

1. Stop the air flow through the EC155.
2. Locate one of the EC155 intake filters in the mesh pocket of the EC100 enclosure.
3. The Santoprene filter assembly is held in place by friction, remove it by simply pulling on the rain diverter. Once removed, make sure the underlying aluminum disk and intake hole are free from debris.
4. Remove the old filter by pulling back on the Santoprene rim that surrounds the filter and pulling up on the filter's edge. Once removed, insert a new filter by pushing the filter in place while pulling back the Santoprene rim. Continue doing this until the filter is well seated.
5. Place the Santoprene filter assembly on the intake's aluminum disk. Press along the Santoprene edge to make sure it is well-seated, see FIGURE 9-5.

NOTE

The standard intake filter has a sintered disk with 20 micron pore size. For dusty sites, an intake filter with 40 micron pores may be ordered, which will increase the lifetime of the filter. Ideally, the appropriate pore size will result in the filter needing replacement at the same time the windows need cleaning (see Section 9.3, *Cleaning Analyzer Windows* (p. 40)). For extremely dusty conditions, lowering the flow rate through the analyzer will further increase the lifetime of the filter, although this will also result in a decrease in frequency response.



FIGURE 9-5. The underside of the intake of the older design sample cell showing the inline filter with rain diverter in black

9.3 Cleaning Analyzer Windows

The windows of the analyzer should be cleaned if the signal strength of CO₂ or H₂O drops below 80% of the original value. (These values may be monitored in the output data, or they can be viewed with *ECMon*.) Clean the windows through the following steps.

1. Stop the air flow through the EC155.
2. Loosen the two captive thumbscrews (one on each end of the EC155), and lift the top portion of the EC155 shell, leaning it back against the lower shell. See FIGURE 9-6.
3. Loosen the thumbscrew on the cable clamp at the back of the analyzer to release the cable, and loosen the two long thumbscrews found above the sample cell. Rotate the latches so that the struts on the analyzer are free to move upwards. See FIGURE 9-7.
4. Lift the analyzer head off the sample cell (see FIGURE 9-8), taking care not to lose the O-rings surrounding the optical windows (see FIGURE 9-9). If an O-ring is lost, two replacement O-rings may be found in the mesh pocket of the EC100 enclosure or new ones may be ordered.
5. Wash the windows with isopropyl alcohol using cotton swabs or a non-scratching tissue or cloth.
6. In most cases, cleaning the sample cell will not be necessary. However, if the inside of the sample cell is visibly dirty, it should be cleaned following the instructions found in Appendix C, *EC155 Sample Cell and Intake Maintenance* (p. C-1).
7. Put the analyzer back in place, making sure the O-rings are still intact. The analyzer's label should be facing out to the side.

8. Rotate the latches back in place to secure the struts down and tighten the long thumbscrews by hand. Position the analyzer cable properly in the cable clamp and tighten the thumbscrew by hand.
9. Put the top portion of the EC155 shell back in place, and tighten the thumbscrews.

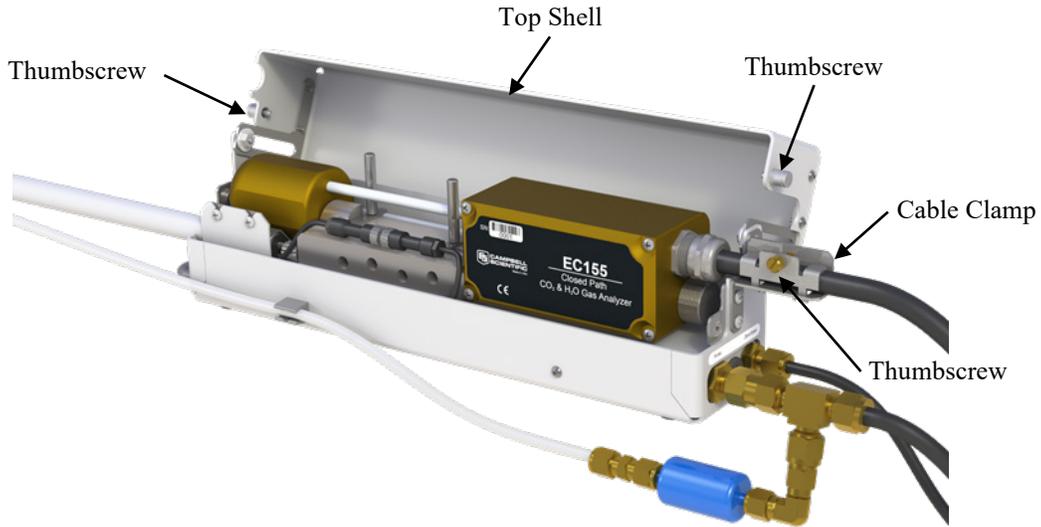


FIGURE 9-6. The EC155 analyzer with the top shell open

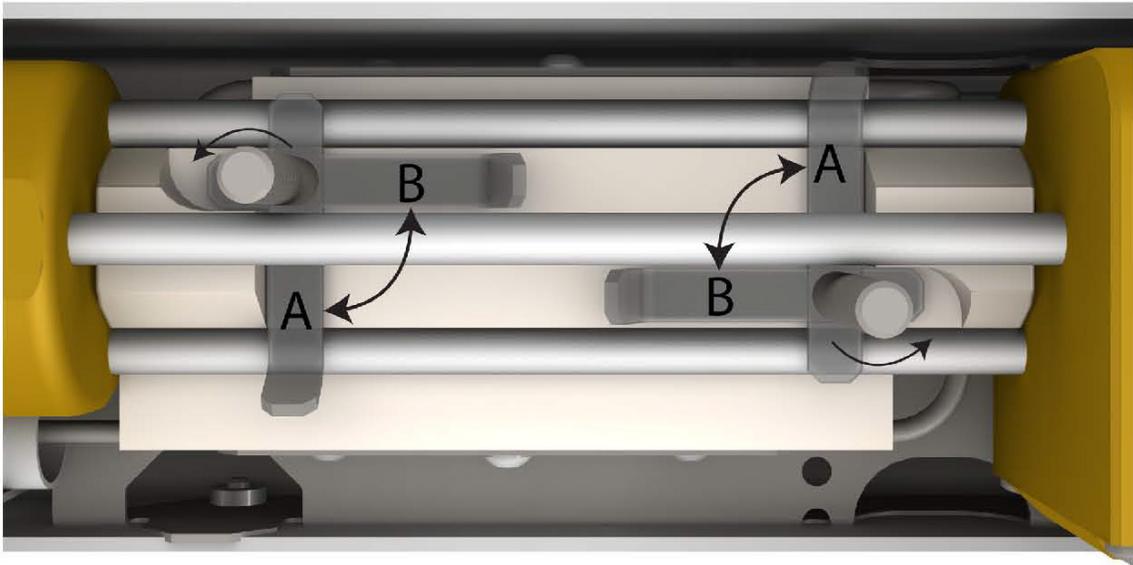


FIGURE 9-7. Thumbscrews above sample cell allowing latches to be spun from position A to position B, freeing struts of analyzer.

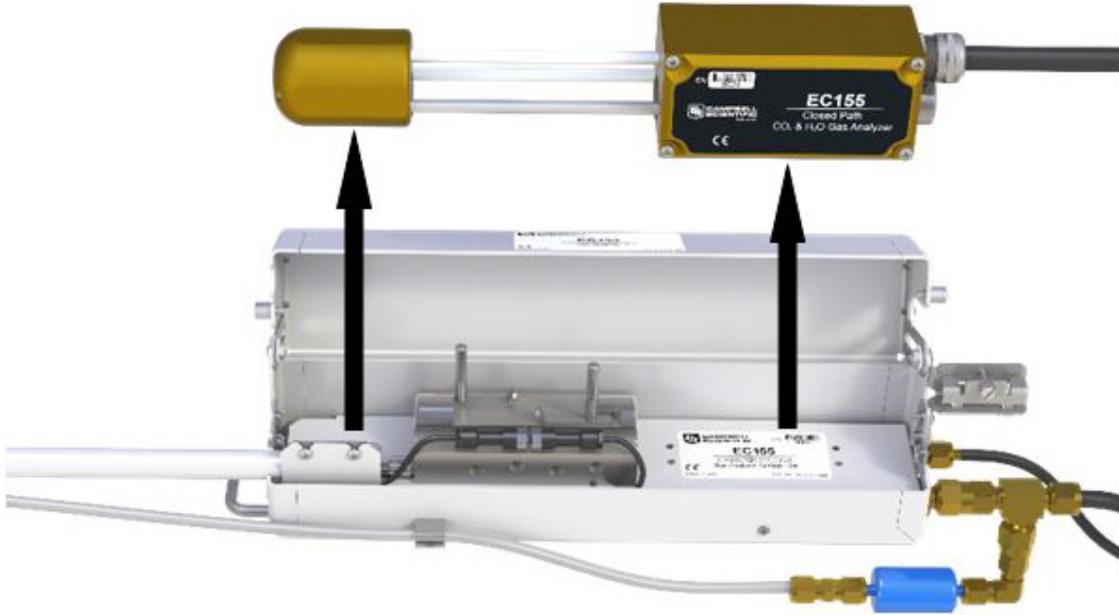


FIGURE 9-8. EC155 analyzer and sample cell with shell top open

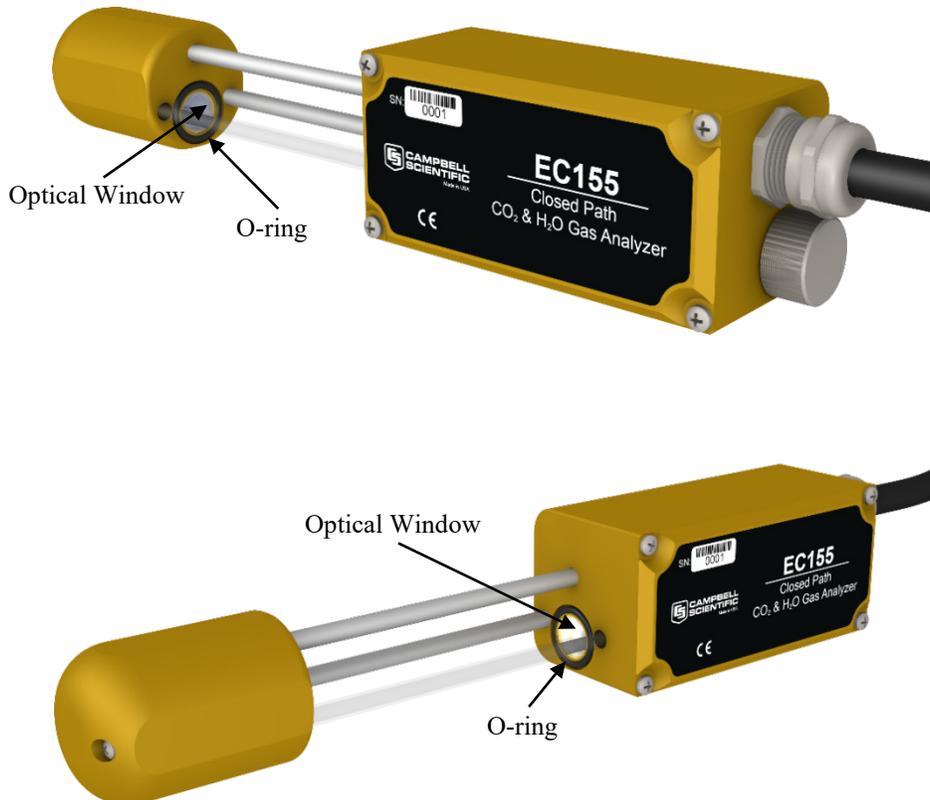


FIGURE 9-9. Analyzer removed from sample cell and shell

9.4 Zero and Span

As is the case with optical instrumentation, the EC155 may drift slightly with exposure to natural elements. Thus, a zero-and-span procedure should be performed occasionally. The first part of the procedure listed below simply measures the CO₂ and H₂O span and zero, without making any adjustments. This allows the CO₂ and H₂O gain factors to be calculated. These gain factors quantify the state of the analyzer before the zero-and-span procedure, and in theory could be used to correct recent measurements for drift. The last part of the zero-and-span procedure adjusts internal processing parameters to correct subsequent measurements.

NOTE

If the EC155 was purchased as part of a CPEC200 closed-path eddy covariance system, consult the CPEC200 manual. The CPEC200 system has an optional valve module to allow the datalogger to automate the zero-and-span procedure.

It is essential that the zero-and-span procedure be done correctly and not rushed; allocate plenty of time for the procedure. During a normal zero-and-span procedure a PC running *ECMon* software is used to monitor and control the EC155. However, the zero-and-span procedure can also be performed using either the *Device Configuration Utility* software or a datalogger running the **EC100Configure()** instruction (see Section 10.2, *EC100Configure() Instruction* (p. 53)).

To check and then set the EC155 zero and span, follow the steps below:

1. Connect the EC100 to a PC with the EC100 USB cable, and launch *ECMon* on the PC. Select the appropriate USB port, and press **Connect**. The main screen should now be reporting real-time CO₂ and H₂O concentrations.
2. Check the differential pressure and signal strengths and service the intake as needed (see Section 9.2, *Intake Cleaning and Filter Replacement* (p. 35)).
3. Check the signal strengths and clean the windows as needed (see Section 9.3, *Cleaning Analyzer Windows* (p. 40)).
4. Verify that the **Gas** LED status light on the EC100 panel is green. Also make sure the analyzer is resting right-side-up. If the zero-and-span procedure is being performed on-site, this should already be the case.
5. Connect the zero-and-span gas to the *Zero/Span* inlet at the back of the analyzer. The zero-and-span gas will be pushed backwards through the EC155 sample cell and exhausted through the intake assembly. If the sample pump is the CPEC200 pump module, it may be left connected and simply shut off. A fraction of the zero-and-span gas will be pushed through the pump, but not enough to affect the equilibration time. Alternatively, the sample pump may be disconnected and the **Pump** connection plugged.
6. Click on the **Zero/Span** button on the main screen of *ECMon*. A real-time graph at the bottom of the window will appear that displays concentrations of CO₂ and H₂O (see FIGURE 9-10).

7. Allow CO₂ span gas to flow through the sample cell. The exact flow rate is not important since sample-cell pressure is being measured. However, a flow rate should be high enough to flush the tubing and sample cell in a reasonable time. If the tubing from the CO₂ span tank to the EC155 is kept short, the CO₂ will equilibrate in several seconds even at relatively low flow rate (< 0.5 LPM). However, if the tubing is long (for example, if the EC155 is left in place at the top of a tower) it may take a few minutes to flush the tube, and a higher flow rate (> 1 LPM) may be useful to reduce the equilibration time.

Once gas begins to flow through the sample cell, watch the graph on *ECMon* for the measurement readings to stabilize. Once stable, write down the reported CO₂ concentration.

NOTE

Optimally the concentration of span CO₂ should be near the concentration of CO₂ being measured in the field. Also, the user is advised to use CO₂ mixtures in dry ambient air for the CO₂ span gas. The use of reference CO₂ gas mixtures in pure nitrogen will lead to errors due to a carrier gas effect on pressure-broadening of the CO₂ absorption lines since oxygen gas has a smaller line-broadening coefficient than nitrogen.

8. Stop the flow of CO₂ span gas, and provide H₂O span gas to the analyzer. A dewpoint generator is often used for this. Allow a relatively high flow rate for the first several minutes to more quickly stabilize the system and then decrease the flow to 0.2 to 0.4 L/min before making the measurement. Higher flow rates should not be used when taking the measurement because back pressure on the dewpoint generator will cause errors. Write down the reported H₂O concentration.

NOTE

As H₂O may adsorb to surfaces inside the tubing and sample cell, allow plenty of time for the system to reach equilibrium.

9. Stop the flow of H₂O span gas, and allow zero air (no CO₂ or H₂O) to flow through the analyzer. Dry nitrogen is often used as zero air. The exact flow rate is not important since sample cell pressure is being measured, however, a flow rate should be high enough to flush the tubing and sample cell within a reasonable time period. Wait for the measurement readings to stabilize and write down the reported values for CO₂ and H₂O concentrations.
10. Examine the measurements that were written down for span CO₂, span H₂O, and zero air. Compute the drift in instrument gain using the following equation:

$$gain = \frac{span_{actual}}{span_{meas} - zero_{meas}}$$

where:

- span_{actual} = known concentration of the span gas
- span_{meas} = measured concentration of the span gas
- zero_{meas} = measured concentration in zero gas.

NOTE

The zero-and-span window of *ECMon*, $\text{span}_{\text{actual}}$ is reported to the right of the box where the user enters the span dew-point temperature. The software calculates $\text{span}_{\text{actual}}$ by taking into account the dew-point temperature and current ambient temperature and pressure. The equations used for this calculation may be found in Appendix B, *Useful Equations* (p. B-1). If drift (offset or gain) for CO₂ or H₂O is excessive, it may be time to replace the desiccant and CO₂ scrubber bottles (see Section 9.5, *Replacing the EC155 Desiccant/CO₂ Scrubber Bottles* (p. 46)).

11. With the zero air still flowing and measurements stabilized, click on the **Zero CO₂ and H₂O** button in the Zero/Span window. This will cause the analyzer to adjust the values of its *CO₂ Zero* and *H₂O Zero* parameters, forcing the CO₂ and H₂O concentrations to read zero. Verify the CO₂ and H₂O concentrations now read zero.
12. Remove the zero-air source and replace it with the CO₂ span gas. Allow the gas to flow through the sample cell. Watch for readings to stabilize.

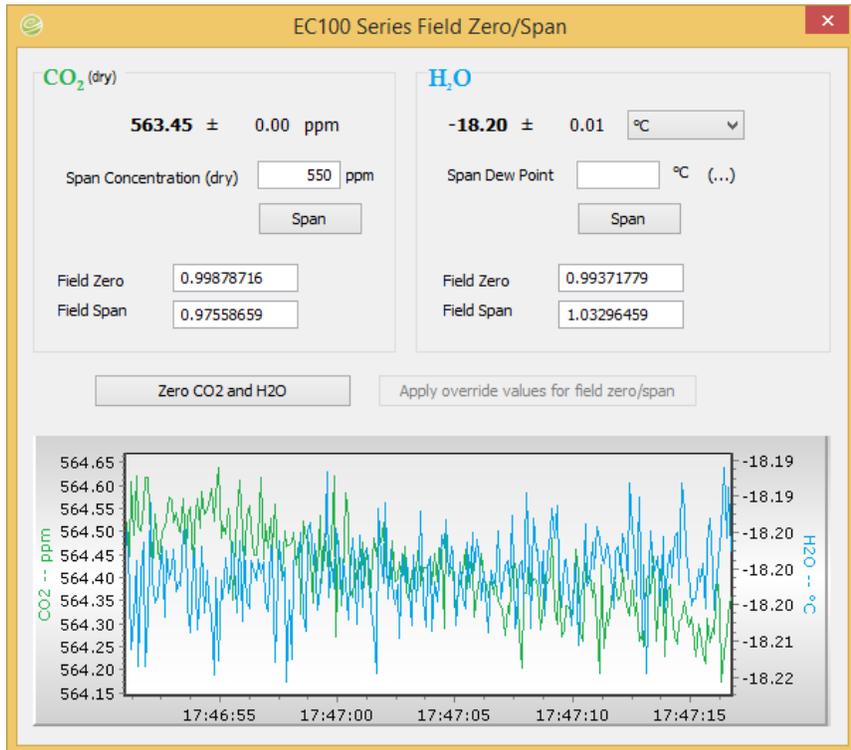


FIGURE 9-10. *ECMon* Zero/Span window

13. Enter the known concentration of CO₂ (in ppm) in the **Span Concentration** box and press **Span**. This will cause the analyzer to adjust the value of its *CO₂ Span* parameter, forcing the measured CO₂ concentration to the value specified. Verify the CO₂ concentration reads the correct value.

14. Replace the CO₂ span gas with an H₂O span gas of known dewpoint. Allow the gas to flow through the sample cell; as before, higher flows may be desired for a couple minutes to more quickly establish equilibrium before resuming a flow between 0.2 and 0.4 LPM. Wait for the readings to stabilize.
15. Enter the known dewpoint (in °C) in the **Span Dew Point** box and press **Span**. This will cause the analyzer to adjust the value of its *H₂O Span* parameter, forcing the measured dewpoint to the value specified. Verify the dewpoint reads the correct value.
16. The zero-and-span procedure is now complete.

9.5 Replacing the EC155 Desiccant/CO₂ Scrubber Bottles

If more than one year has passed since replacing the desiccant/scrubber, or if zero-and-span readings have drifted excessively (see Section 9.4, *Zero and Span* (p. 43), above), the desiccant/scrubber bottles within the EC155 analyzer head should be replaced as follows:

1. Remove the analyzer in the same way as explained in Section 9.3, *Cleaning Analyzer Windows* (p. 40), of this manual.
2. Unscrew the large metal plug found at the base of the analyzer next to the analyzer cable; it should only be hand-tight (see FIGURE 9-11). Once the plug is removed, tip the analyzer up so the desiccant/scrubber bottle falls out. Insert a new bottle lid-first into the analyzer. Firmly screw the plug back in place.

CAUTION

EC155 instruments sold prior to July 2017 were sold with scrubber bottles that contained strong oxidizing agents. Avoid direct contact with the chemicals inside the bottles. Ensure the work area is well ventilated and free of any reactive compounds including liquid water. Store used chemical bottles in a sealed container until disposal.

3. On the other end of the analyzer, remove the two seal-screws from the metal cap (see FIGURE 9-12). Carefully pull the cap off. Tip the analyzer up so the desiccant/scrubber bottle falls out. Insert a new bottle lid-first. Push the cap back on, and use two new seal-screws (included with replacement desiccant/scrubber bottles) to hold the cap in place.

CAUTION

While the metal cap is removed, avoid touching the detector and its electronics.

4. Insert the analyzer back into place, making sure to latch the analyzer's struts down. Do not operate the analyzer for at least 24 hours (longer if in humid environments) to give the chemicals time to purge the air inside the analyzer. A zero-and-span procedure should then be performed before resuming measurements.

Dispose of any chemical bottles according to local and federal regulations. More information about the chemicals can be found in Appendix E, *Safety Data Sheets (SDS)* (p. E-1).



FIGURE 9-11. Replacing the source housing desiccant/scrubber bottle (replacement bottles purchased in or after July 2017 may appear different than in the figure)

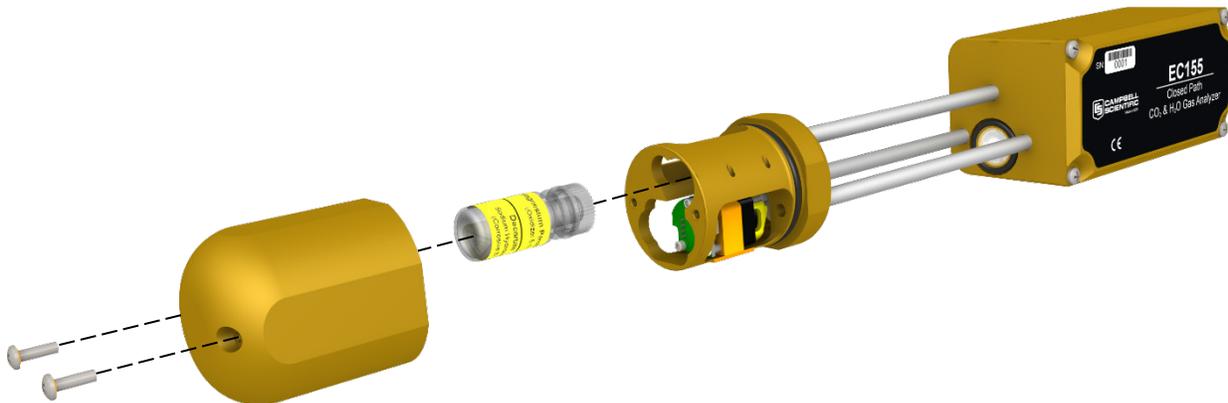


FIGURE 9-12. Replacing the detector housing desiccant/scrubber bottle (replacement bottles purchased in or after July 2017 may appear different than in the figure)

9.6 Factory Recalibration

When the EC155 is manufactured, it goes through an extensive calibration process, covering a wide range of temperatures, pressures, and gas concentrations. All CO₂ calibration gases used in this process are mixtures of CO₂ in ambient air traceable to the WMO Mole Fraction Scale maintained by the Central Carbon Dioxide Laboratory and the Carbon Cycle Greenhouse Gases Group of the Global Monitoring Division/National Oceanographic and Atmospheric Administration in Boulder, CO, USA.

After an extended period of time in the field, the EC155 may need to undergo this factory calibration again in order to ensure valid measurements. When recalibration is deemed necessary, contact Campbell Scientific, Inc.

For the CSAT3A, refer to the CSAT3A instruction manual for information on recalibration.

10. Data Collection and Data Processing

Data from the EC155 is collected through the EC100 and then archived onto a datalogger. A common instrument configuration is to program a datalogger to retrieve and collect raw data from the EC155, to be used for post processing, for which various programs have been developed.

More recently, programs have been developed that efficiently record and correctly process data from instruments such as the EC155, as well as compile them with data from other, complementary instruments. Campbell Scientific has developed a program, *EasyFlux™ DL*, that both records and processes raw data from the EC155 to provide useful measurements immediately. An overview of both approaches is given in the sections below.

10.1 Data Collection and Processing with *EasyFlux DL*

EasyFlux DL is an open source *CRBasic* program that allows a CR6 or CR3000 datalogger to collect fully corrected measurements from an EC155 instrument. The program is compatible with other GPS and energy balance sensors which, in combination, can report corrected fluxes for CO₂, latent heat (H₂O), sensible heat, ground surface heat flux, and momentum. The program processes the EC data using commonly used corrections in the scientific literature. For detailed information about downloading, installing, and configuring the free program, refer to the *EasyFlux DL* manual located at www.campbellsci.com/easyflux-dl.

Of particular note is the manner in which *EasyFlux DL* processes information from the sonic anemometer and is useful to understand when considering how to situate the analyzer and anemometer at a given site.

EasyFlux DL reports the wind direction in both the sonic coordinate system (a right-handed coordinate system, FIGURE 10-1) and in the compass coordinate system (a left-handed coordinate system, FIGURE 10-2). To report the wind direction in the compass coordinate system, the orientation of the sonic must be known. The sonic coordinate system is relative to the sonic itself and does not depend on the sonic's orientation. The compass coordinate system is fixed to Earth. For the *EasyFlux DL* program to compute the correct compass wind direction, the azimuth of the sonic negative x-axis must be entered into the program. The output value for the compass coordinate system is **WD** and the output value for the sonic coordinate system is **WD_Sonic**. The program default value for the variable **sonic_azimuth** is **0**. To report a true compass wind direction, an appropriate value for **sonic_azimuth** must be entered into the program. The default is appropriate only if the sonic is mounted such that the negative x-axis points to the north.

NOTE

Remember to account for magnetic declination at the installation site. See Appendix D, *CSAT3A Orientation (p. D-1)* for details.

The variable **sonic_azimuth** can be changed in *LoggerNet* or by using a CR100KD keypad. It can be changed in *LoggerNet* by connecting the datalogger to a computer, opening *LoggerNet*, and going into the **Public** data

table and changing the value in the **sonic_azimuth** field. Note that if the units of the variables are being displayed in the field, the units must be deleted before entering a value. If a new value is attempted to be sent along with the units in the field, then a change will not be made. To change it on the keypad, go to the **Site Var Settings** menu, then go to **sonic_azimuth** and enter a new value. Once a value is entered, the value is saved in the CPU. The program default of **0** for **sonic_azimuth** is used only if a site-specific value has not been entered using the keyboard or through *LoggerNet*.

FIGURE 10-1 and FIGURE 10-2 show the compass and sonic coordinate system. Both figures show the sonic's negative x-axis pointing to the west (compass azimuth of 270°). The wind direction is measured in degrees clockwise from due north. In the compass coordinate system, the wind direction (**WD**) is 200. To calculate the wind direction in FIGURE 10-1, the orientation of the sonic anemometer relative to due north is needed in the program. FIGURE 10-2 is in a right-handed coordinate system, and the wind vector direction is measured in degrees counterclockwise from the positive x-axis. Therefore, the wind vector direction (**WD_sonic**) is 70°.

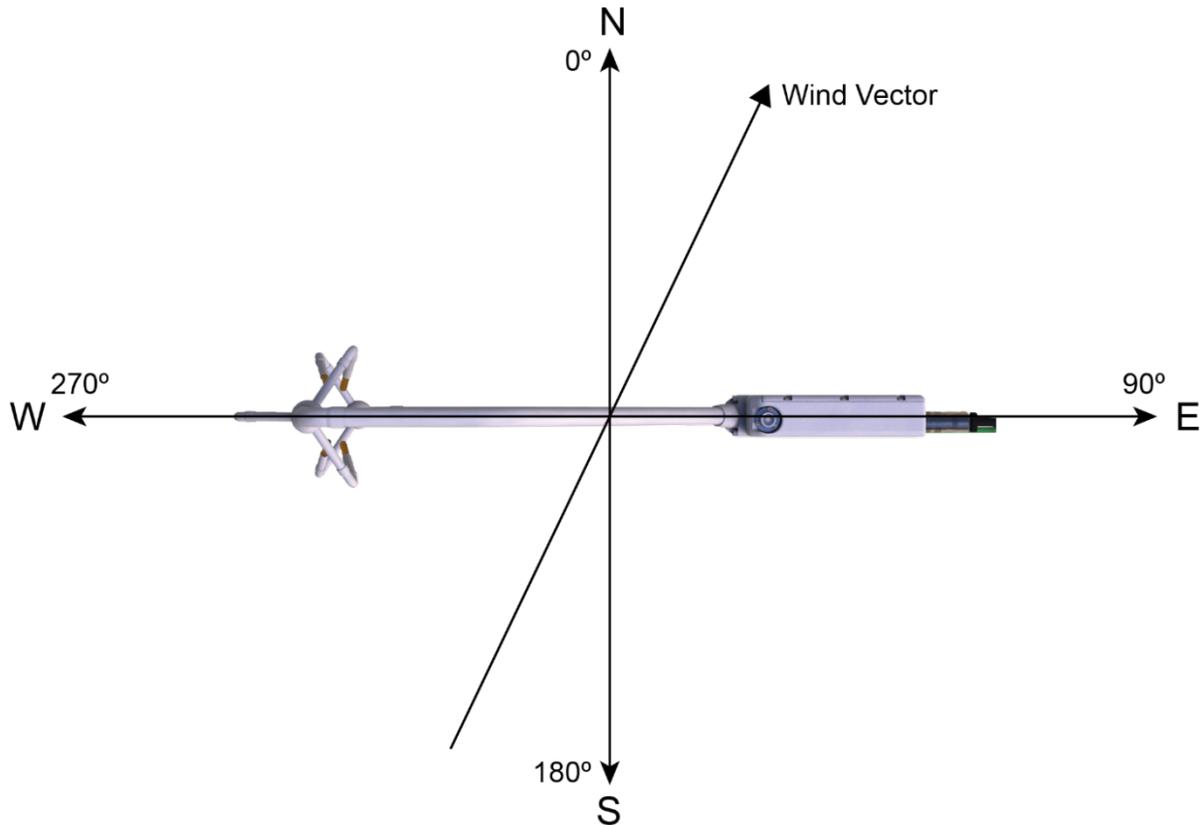


FIGURE 10-1. Compass coordinate system, compass wind direction is 200°. The sonic azimuth of the anemometer is 270°

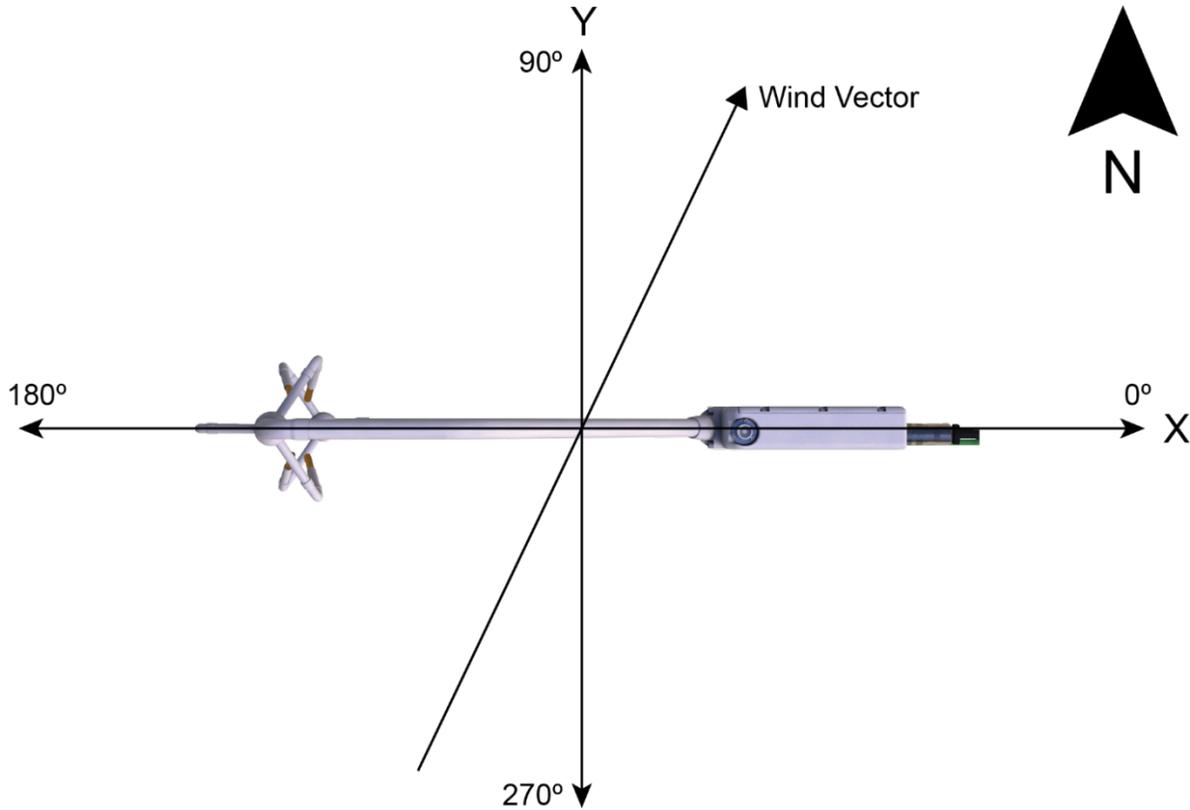


FIGURE 10-2. Right-handed coordinate system, horizontal wind vector angle is 70°

10.2 Datalogger Programming with *CRBasic*

The datalogger of the EC155 is programmed in the *CRBasic* language, which features two instructions for communication with the EC100 via SDM. The first instruction is **EC100()**, which reads measurement data from the EC100. The second is the **EC100Configure()**, which receives and sends configuration settings.

10.2.1 EC100() Instruction

The EC100() instruction is used to retrieve data from the EC155 via SDM. The instruction syntax is:

EC100 (*Dest*, *SDMAddress*, *EC100Cmd*)

Dest is the input variable name in which to store data from the EC155. The length (i.e., number of data elements) of the input variable array will depend on the selected value for *EC100Cmd*. A value of -99999 will be loaded into *Dest(l)* if a signature error on SDM data occurs.

Command	Input Variable Length
0	8
1	12
2	13

SDMAddress defines the address of the EC155 with which to communicate. Valid SDM addresses are 0 through 14. Address 15 is reserved for the **SDMTrigger()** instruction.

EC100Cmd is a parameter that requests the data to be retrieved from the analyzer. The results for the command will be returned in the array specified by the *Dest* parameter. A numeric code is entered to request the data, as shown in TABLE 10-1.

EC100Cmd	Data Field	Description	Units
0, 1, 2,	1	Ux	m/s
	2	Uy	m/s
	3	Uz	m/s
	4	Sonic Temperature	°C
	5	Sonic Diagnostic Flag	
	6	CO ₂	µmol CO ₂ /mol
	7	H ₂ O	mmol H ₂ O/mol
	8	Gas Diagnostic Flag	
1, 2	9	Sample Cell Temperature	°C
	10	Sample Cell Pressure ^{1/}	kPa
	11	CO ₂ Signal Strength	nominally 0.0 ≤ strength ≤ 1.0
	12	H ₂ O Signal Strength	nominally 0.0 ≤ strength ≤ 1.0
2	13	Sample Cell Pressure Differential	kPa

^{1/} The newer design EC155 sample cell (serial numbers 2000 and greater) uses an absolute pressure sensor to measure sample cell pressure, but the pressure differential relative to ambient pressure is still reported. This provides consistency with the older design outputs and is useful in monitoring potential flow constrictions in the intake.

As shown, all output modes give two diagnostic values, the **Sonic Diagnostic Flag** and the **Gas Diagnostic Flag**. The values contain a bit field, with each bit representing a monitored condition. When a certain condition is detected, the corresponding bit is set. The value remains set until the event that caused the condition is no longer present. TABLE 10-2 and TABLE 10-3 describe the bits in the sonic diagnostic flag and the gas diagnostic flag, respectively.

TABLE 10-2. Bits in the Sonic Diagnostic Flag

Bit	Hex Value	Decimal	Name	Function
0	0x1	1	Low Amp	Amplitude is too low
1	0x2	2	High Amp	Amplitude is too high
2	0x4	4	Tracking	Poor signal lock
3	0x8	8	Hi 3 Axis DC	Delta temperature exceeds limits
4	0x10	16	Acquiring	Acquiring ultrasonic signals
5	0x20	32	Cal Mem Err	Sonic head calibration signature error

TABLE 10-3. Bits in the Gas Diagnostic Flag

Bit	Hex Value	Decimal	Name	Function
0	0x1	1	Bad Data	Data are suspect (there is an active diagnostic flag)
1	0x2	2	Sys Fault	General system fault
2	0x4	4	Sys Startup	Gas analyzer is starting up
3	0x8	8	Motor Speed	Motor speed outside of limits
4	0x10	16	TEC Temp	TEC temperature exceeds limits
5	0x20	32	Light Power	Source power exceeds limits
6	0x40	64	Light Temp	Invalid source temperature
7	0x80	128	Light I	Source current exceeds limits
8	0x100	256	Power Off	Gas head not powered
9	0x200	512	Chan Err	Gas input data out of sync with home pulse
10	0x400	1024	Cell Temp	Invalid sample cell temperature
11	0x800	2048	Cell Press	Invalid sample cell pressure
12	0x1000	4096	CO ₂ I	CO ₂ I exceeds limits
13	0x2000	8192	CO ₂ I _o	CO ₂ I _o exceeds limits
14	0x4000	16384	H ₂ O I	H ₂ O I exceeds limits
15	0x8000	32768	H ₂ O I _o	H ₂ O I _o exceeds limits
16	0x10000	65536	CO ₂ I _o Var	Moving variation in CO ₂ I _o exceeds limits
17	0x20000	131072	H ₂ O I _o Var	Moving variation in H ₂ O I _o exceeds limits
18	0x40000	262144	CO ₂ I _o Ratio	CO ₂ signal level too low
19	0x80000	524288	H ₂ O I _o Ratio	H ₂ O signal level too low
20	0x100000	1048576	Cal Mem Err	Gas head calibration signature error
21	0x200000	2097152	Heater Control	Heater control error
22	0x400000	4194304	Diff Pressure	Differential pressure exceeds limits

10.3 EC100Configure() Instruction

This instruction is another way, besides *ECMon* and *Device Configuration Utility*, to retrieve and modify settings. *ECMon* and *Device Configuration Utility* are user-interactive, while the **EC100Configure()** instruction allows automated control under *CRBasic* datalogger programming.

EC100Configure() is a processing instruction. Whether running in pipeline mode or sequential mode the datalogger will execute the instruction from processing. This functionality allows the instruction to be placed in conditional statements. Running from processing also introduces ramifications when attempting to execute the **EC100Configure()** instruction while other SDM instructions are executing in pipeline mode. This instruction locks the SDM port during the duration of its execution. If the pipelined SDM task sequencer needs to run while the SDM is locked, it will be held off until the instruction completes. This locking will likely result in skipped scans when reconfiguring an EC155.

For the EC155 to save settings, it must go through a lengthy write-read-verify process. To avoid saving the settings after each set command, the result code can be used to determine if any settings were modified from their original value. When a change is detected the save settings command (command code 99) can then be sent to the EC155. The *DestSource* parameter variable should be set to 2718 to save the settings. The reception of this command is acknowledged but since it takes up to a second to complete, a successful return code does not mean that all of the data was successfully written to the appropriate non-volatile memory.

The instruction syntax is:

EC100Configure(*Result*,*SDMAddress*,*ConfigCmd*,*DestSource*)

Result is a variable that contains a value indicating the success or failure of the command. A result code of 0 means that the command was successfully executed. If reading a setting, 0 in the result code means that the value in the *DestSource* variable is the value the desired setting has in the EC155. When writing a setting, if the result code is 0, the value and setting were compatible, but the value was not changed because it contained the same value that was sent. A return code of 1 from the set operation means that the value was valid, different, set and acknowledged. This allows *CRBasic* code to control whether or not to save the settings. *NAN* (not a number) indicates that the setting was not changed or acknowledged or a signature failure occurred.

SDMAddress defines the address of the EC155 to configure. Valid SDM addresses are 0 through 14. Address 15 is reserved for the **SDMTrigger()** instruction.

ConfigCmd is a variable that indicates whether to get or set a setting. The options are listed in TABLE 10-4.

DestSource is a variable that will contain the value to read when getting a setting, or that will contain the value to send when writing a setting to the EC155.

TABLE 10-4. ConfigCmd Values for Setting and Retrieving Settings

ConfigCmd Variable		Setting Description (some settings list possible values for the DestSource variable)
Set	Retrieve	
0	100	Bandwidth: 5 = 5 Hz, 10 = 10 Hz, 12 = 12.5 Hz, 20 = 20 Hz
1	101	ECMon Output Rate: 10 = 10 Hz, 20 = 20 Hz, 99 = motor spin rate in Hz (for example, 60 Hz)
2	102	Pressure Sensor: 0 = EC100 Basic, 1 = User-Supplied, 2 = EC100 Enhanced, 3 = None (use fixed value)
3	103	Differential Pressure: 0 = Disable, 1 = Enable, 2 = Auto-select
4	104	Fixed Pressure Value
5	105	Pressure Offset
6	106	Pressure Gain
7	107	Temperature Sensor: 0 = EC150 Temperature Probe 1 = EC155 Sample Cell Thermistor 2 = EC155 Sample Cell Thermocouple 3 = None (use fixed value) 4 = Auto-Select
8	108	Fixed Temperature Value
9	109	Unprompted Output Mode: 0 = Disable, 1 = USB, 2 = RS-485
10	110	RS-485 Baud Rate
11	111	Span/Zero Control: 0 = Inactive, 1 = Zero, 2 = Span CO ₂ , 3 = Span H ₂ O (see Section 10.2.1, <i>ConfigCmd 11 Zero-and-Span Control</i> (p. 55))
12	112	CO ₂ Span Concentration
13	113	H ₂ O Span Dewpoint Temperature
14	114	CO ₂ Zero Coefficient
15	115	CO ₂ Span Coefficient
16	116	H ₂ O Zero Coefficient
17	117	H ₂ O Span Coefficient
18 or 218	118	Heater Voltage (0 to 4.0V, -1 = Off) (see Section 10.2.2, <i>ConfigCmd 18 Heater Voltage</i> (p. 55))
20	120	Analog Output Enable: 0 = Disable, 1 = Enable
21	121	PowerDown: 0 = Gas Head On, 1 = Gas Head Off
22	122	Unprompted Output Rate: 10 = 10 Hz, 20 = 20 Hz, 99 = motor spin rate
24	124	EC155 Pressure Sensor Type: 0 = Differential, 1 = Absolute
25	125	Sonic Transducer Shadow Correction: 0 = Disable, 1 = Enable
99	N/A	Save Settings to EEPROM memory

10.3.1 ConfigCmd 11 Zero-and-Span Control

To perform zeroing of CO₂ and H₂O, *ConfigCmd 11* is set to 1. After the EC155 completes the zero, it will write the value to -1. The datalogger can poll this value or simply wait for a period of time to allow the zeroing to complete. To perform CO₂ span, the CO₂ Span Concentration setting (*ConfigCmd 12*) must be written to the proper value in ppm CO₂ prior to setting the Span/Zero Control setting (*ConfigCmd 11*) to 2. After the CO₂ span is completed, the value of the Span/Zero Control setting will change to -2. H₂O span is similar to CO₂. First the H₂O dewpoint value (*ConfigCmd 13*) must be written to the desired value. Then the Span/Zero Control setting is set to 3. After the EC155 completes the span, the span control setting is written as -3. *ConfigCmd's 14* through *17* automatically store the results of the zero-and-span procedure. Each result is a coefficient used in the gas analyzer's algorithms for calculating gas concentrations.

10.3.2 ConfigCmd 18 Heater Voltage

Normally the **EC100Configure()** instruction is run in the datalogger's processing task. Skipped scans can occur when the **EC100Configure()** instruction executes. When changing operational parameters, these skipped scans are acceptable. However, it may not be acceptable when changing the heater voltage. *ConfigCmd 218* allows the **EC100Configure()** instruction to operate in the SDM task, thus avoiding skipped scans. When using *ConfigCmd 218*, the command must be a constant and the instruction cannot be placed in a conditional statement.

This setting gives the voltage applied to the intake heater. It can be set to -1 to disable the heater, or set it to any voltage between 0 and 4.0 V. The heater prevents condensation in the intake tube.

The resistance of the heater in the intake assembly is 20 ohms, so the heater power will be given by:

$$P_H = \frac{V^2}{20}$$

The maximum power (at 4.0 V) is 0.8 W. The heater may be operated continuously at full power, over the full range of operating temperatures. If ambient conditions are dry enough to prevent condensation without heating the intake, the power may be turned down to conserve power. Note that the CPEC200 system has a default to power the intake heater at its maximum voltage to prevent condensation.

10.4 Example CRBasic Program

CRBasic Example 10-1. CR3000 Example Program

```
'CR3000 Series Datalogger
'CR3000 Series Datalogger

Public sonic_irga(13)
Alias sonic_irga(1) = Ux
Alias sonic_irga(2) = Uy
Alias sonic_irga(3) = Uz
Alias sonic_irga(4) = Ts
Alias sonic_irga(5) = diag_sonic
Alias sonic_irga(6) = CO2
Alias sonic_irga(7) = H2O
Alias sonic_irga(8) = diag_irga
Alias sonic_irga(9) = cell_tmpr
Alias sonic_irga(10) = cell_press
Alias sonic_irga(11) = CO2_sig_strgth
Alias sonic_irga(12) = H2O_sig_strgth
Alias sonic_irga(13) = diff_press

Units Ux = m/s
Units Uy = m/s
Units Uz = m/s
Units Ts = C
Units diag_sonic = arb
Units CO2 = umol/mol
Units H2O = mmol/mol
Units diag_irga = arb
Units cell_tmpr = C
Units cell_press = kPa
Units CO2_sig_strgth = arb
Units H2O_sig_strgth = arb
Units diff_press = kPa

DataTable (ts_data, TRUE, -1)
  DataInterval (0,0,mSec,10)

  Sample (13,Ux,IEEE4)
EndTable

BeginProg
  Scan (100,mSec,0,0)
  EC100 (Ux,1,2)
  CallTable ts_data
  NextScan
EndProg
```

11. Theory of Operation

The EC155 is a non-dispersive mid-infrared absorption analyzer. Infrared radiation is generated in the larger block of the analyzer before propagating through a 12 cm sample cell. Chemical species located within the sample cell will absorb radiation at characteristic frequencies. A mercury cadmium telluride (MCT) detector in the smaller block of the gas analyzer measures the decrease in radiation intensity due to absorption, which can then be related to analyte concentration using the Beer-Lambert Law:

$$P = P_0 e^{-\epsilon cl}$$

Where:

- P = irradiance after passing through the optical path
- P₀ = initial irradiance
- ε = molar absorptivity
- c = analyte concentration, and
- l = path length.

In the EC155, radiation is generated by applying constant power to a tungsten lamp, which acts as a 2200 K broadband radiation source. Specific wavelengths are then selected using interference filters located on a spinning chopper wheel. For CO₂, radiation with a wavelength of 4.3 μm is selected, as it corresponds to the molecule's asymmetric stretching vibrational band. For H₂O, radiation at 2.7 μm, corresponding to water's symmetric stretching vibrational band, is used.

The EC155 is a dual wavelength single beam analyzer; thus, rather than using a separate reference cell and detector, the initial intensity of the radiation is calculated by measuring the intensity of nearby, non-absorbing wavelengths (4 μm for CO₂ and 2.3 μm for H₂O). These measurements account for any source and detector aging and window contamination.

The chopper wheel spins at a rate of 60 revolutions per second, and the detector is measured 512 times per revolution. The detector is maintained at –40 °C using a three-stage thermoelectric cooler and is coupled to a low noise pre-amp module.

The EC100 electronics digitize and process the detector data (along with ancillary data such as sample-cell temperature and pressure) to give the CO₂ and H₂O concentration for each chopper wheel revolution (60 Hz), filtered to the user-specified bandwidth. The EC100 also synchronously measures and processes data from an optional CSAT3A 3D sonic anemometer head.

Appendix A. Filter Bandwidth and Time Delay

The EC100 measures CO₂ and H₂O from the EC155 gas analyzer head (as well as wind velocity and sonic temperature from the optional CSAT3A sonic head) at 60 Hz and then applies a user-selectable low-pass filter. The available filter bandwidths are 5, 10, 12.5, and 20 Hz. FIGURE A-1 shows the amplitude response of these filters. The EC100 filters provide a flat pass band, a steep transition from pass band to stop band, and a well-attenuated stop band. FIGURE A-2 compares the EC100 10-Hz filter to a 50-msec moving average filter with approximately the same bandwidth.

The ideal eddy-covariance filter is one that is wide enough to preserve the low-frequency signal variations that transport flux and narrow enough to attenuate high-frequency noise. In addition, to minimize aliasing (the misinterpretation of high-frequency variation as lower-frequency variation) the measurement bandwidth must be less than half of the sample rate, or the datalogger scan rate. Two factors complicate choosing the ideal eddy-covariance bandwidth. First, the flux signal bandwidth varies from one installation to another, and the flux signal bandwidth varies with mean wind speed at a given installation. Second, the fast sample rate required to anti-alias a desired signal bandwidth may result in large, unwieldy data sets.

Fortunately, the covariance calculation itself relaxes the need for the ideal bandwidth. First, the time-averaged (typically thirty-minute) covariance calculations inherently reduce noise, and second, aliasing does not degrade the accuracy of covariance calculations. Therefore, the factory default for the EC100 bandwidth (20 Hz) is rather wide to preserve the signal variations that transport flux, and that bandwidth is suitable for most flux applications. Additional bandwidths are available for experimenters desiring to match the EC100 filter bandwidth to their data acquisition sample rate to avoid aliasing. In this case, the selected bandwidth should be one-half of the sample rate (or datalogger scan rate), and experimenters should be careful to avoid attenuation of flux-carrying signals.

The EC100 electronics synchronously sample the gas in the EC155 sample cell and the CSAT3A sonic head. However, delays induced by the intake assembly must be accounted for. The exact delay will depend on the length and size of the intake tubing and the pump flow rate. This delay needs to be experimentally determined by shifting the time delay until the covariance of the vertical wind and the gas concentrations are maximized.

Experimenters wishing to synchronize their EC100 data with other measurements in the data acquisition system must account for the time delay of the EC100 filter. TABLE A-1 shows the delay for each of the filter bandwidths. The EC100 provides a constant time delay for all spectral components within each filter's pass band.

The following example shows how to use TABLE A-1. To synchronize EC100 data to other datalogger measurements when the datalogger scan rate is 10 Hz (100-msec scan interval) and the EC100 bandwidth is set to 20 Hz (a 200-msec time delay from TABLE A-1), delay the non-EC100 data by two datalogger scans (time delay divided by scan interval) to match the EC100 data. For the

best synchronicity, choose a datalogger scan interval that, when multiplied by an integer, equals the EC100 filter delay.

NOTE

Because the time delay for the 12.5 Hz bandwidth filter is a prime number, EC100 measurements with this bandwidth cannot be synchronized as well as other bandwidths. For this reason, the 12.5 Hz bandwidth should be avoided if other fast measurements are being made by the datalogger and will need to be synchronized with the EC100 measurements.

The EC100 measures the gas and wind data at 60 Hz, and the 60-Hz data are down-sampled to the datalogger's scan rate through SDM communications (see Section 8, *EC100 Outputs* (p. 31)). This process synchronizes the EC100 gas and wind data with other signals measured by the datalogger to within ± 8.33 ms (plus or minus one-half of the inverse of 60 Hz). Alternatively, when sending data to a non-Campbell data acquisition system, the EC100 down-samples its USB and RS-485 outputs to a user-selectable rate of 10, 20, or 60 Hz. Although the gas and wind data from the EC100 remain synchronized with one another, the user must consider the down-sampled output interval when synchronizing the EC100 data with other measurements in their system. Slower output intervals will increase the asynchronicity of EC100 data with other system measurements.

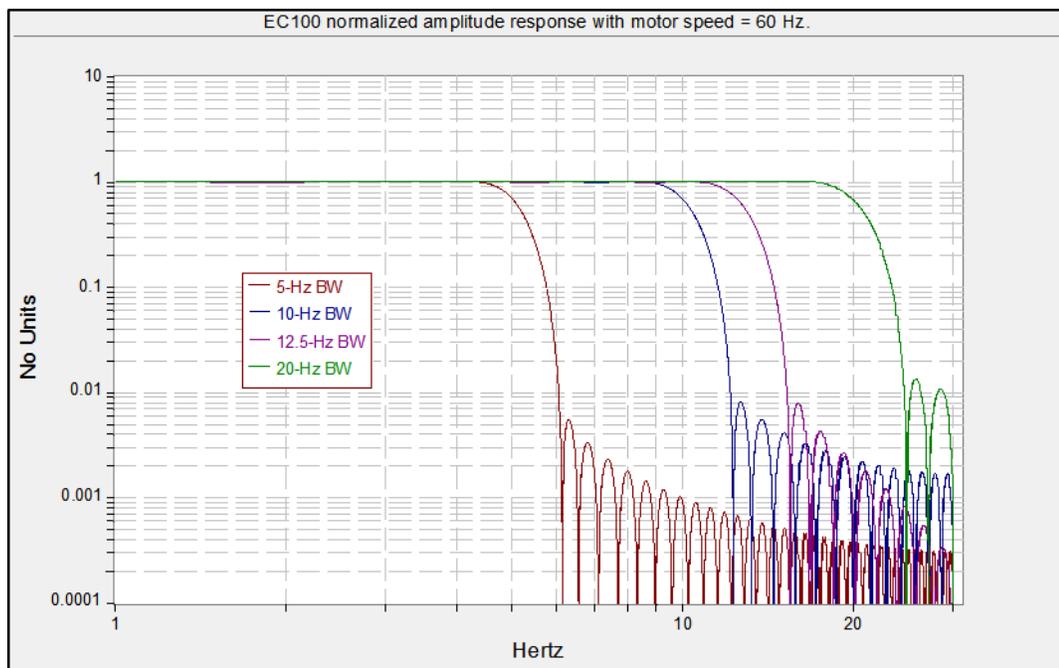


FIGURE A-1. Frequency and amplitude response of the EC100 filter at various bandwidths

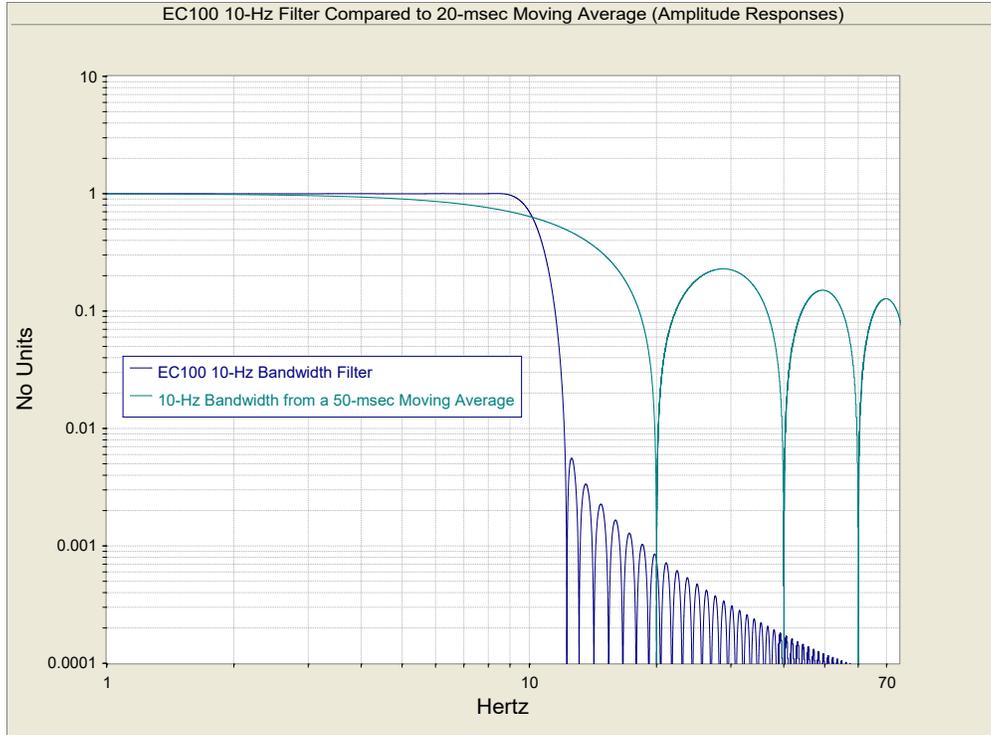


FIGURE A-2. Frequency response comparison of the EC100 10-Hz bandwidth and a 50-msec moving average

TABLE A-1. Filter Time Delays for Various Bandwidths	
Bandwidth (Hz)	Time Delay (ms)
5	800
10	400
12.5	317
20	200

Appendix B. Useful Equations

The following table lists all the variables and constants used in the equations below:

Table of Variables and Constants		
Variable or Constant	Description	Units
ρ_c	CO ₂ Mass Density	mg CO ₂ ·m ⁻³
ρ_v	H ₂ O Mass Density	g·m ⁻³
ρ_d	Mass Density of Dry Air	g·m ⁻³
X_c	CO ₂ Molar Mixing Ratio (concentration relative to dry air)	μmol CO ₂ ·mol ⁻¹
X_v	H ₂ O Molar Mixing Ratio (concentration relative to dry air)	mmol H ₂ O·mol ⁻¹
M_c	Molecular Weight of CO ₂	44 mg CO ₂ ·mmol ⁻¹
M_d	Molecular Weight of dry air	0.029 g·mmol ⁻¹
M_v	Molecular weight of H ₂ O	0.018 g H ₂ O·mmol ⁻¹
P	Ambient Pressure	kPa
R	Universal Gas Constant	8.3143·10 ⁻⁶ kPa·m ³ K ⁻¹ ·mmol ⁻¹
T	Ambient Temperature	°C
e	Vapor Pressure	kPa
f	Enhancement Factor	Arbitrary
T_d	Dewpoint Temperature	°C
T_{d_tmp}	Temporary variable for dewpoint calculation	Arbitrary

Mass Density from Molar Mixing Ratios

$$\rho_c = \frac{X_c M_c}{10^6} \left(\frac{P}{R(T + 273.15)} - \frac{\rho_v}{M_v} \right) \quad (\text{B-1})$$

$$\rho_v = \frac{X_v P M_v}{R(T + 273.15)(1000 + X_v)} \quad (\text{B-2})$$

$$\rho_d = \frac{(P - e) M_d}{R(T + 273.15)} \quad (\text{B-3})$$

$$\rho_d = \frac{\left(P - \frac{X_v P}{1000 + X_v} \right) M_d}{R(T + 273.15)} \quad (\text{B-4})$$

$$\rho_d = \left(\frac{PM_d}{R(T + 273.15)} \right) \left(1 - \frac{X_v}{1000 + X_v} \right) \quad (\text{B-5})$$

Dewpoint from Molar Mixing Ratio

$$T_d = \frac{240.97 T_{d_tmp}}{17.502 - T_{d_tmp}} \quad (\text{B-6})$$

$$T_{d_tmp} = \ln \left(\frac{X_v P}{0.61121 \cdot f (1000 + X_v)} \right) \quad (\text{B-7})$$

$$f = 1.00072 + (3.2 \times 10^{-5})P + (5.9 \times 10^{-9})PT^2 \quad (\text{B-8})$$

Water Vapor Molar Mixing Ratio from Dewpoint

$$X_v = \frac{e}{P - e} 1000 \quad (\text{B-9})$$

$$e = 0.61121 \cdot f \cdot \text{EXP} \left(\frac{17.502 T_d}{240.97 + T_d} \right) \quad (\text{B-10})$$

Water Vapor Mass Density from Dewpoint

$$\rho_v = \frac{(0.018)(0.61121)f}{R(T + 273.15)} \text{EXP} \left(\frac{17.502 T_d}{240.97 + T_d} \right) \quad (\text{B-11})$$

Vapor Pressure from Molar Mixing Ratio and Water Vapor Density

$$e = \frac{X_v P}{1000 + X_v} \quad (\text{B-12})$$

$$e = \frac{\rho_v R (T + 273.15)}{M_v} \quad (\text{B-13})$$

Equations (1) and (2) were derived from Leuning, 2004; Eq. 6.23.

Equations (6) - (8) and (10) - (11) were derived from Buck, 1981; Eq. 2a, 3a, and 6.

Appendix C. EC155 Sample Cell and Intake Maintenance

The following steps can be undertaken when the sample cell and intake tube becomes dirty, or as part of routine maintenance of the EC155. Refer to Section 9.3, *Cleaning Analyzer Windows (p. 40)*, for figures and instructions for accessing and removing the analyzer from the sample cell.

C.1 Cleaning Sample Cell

1. Turn off the pump.
2. Power down the analyzer.
3. Remove the analyzer from the sample cell.
4. Use water or alcohol on a soft cotton swab to clean the inside of the sample cell.

NOTE

Take care not to let the water or alcohol drip down into the holes at ends of the sample cell. Each end has a small passage that connects to the pressure sensor. These passages can become plugged by residue carried by the water or alcohol. This problem can be avoided by using cotton swabs that are slightly moist, not saturated. However, if more aggressive cleaning is needed, invert the sample-cell assembly during cleaning so any liquid drains away from these passages.

C.2 Cleaning Intake Tube

The newer design of the EC155 sample cell (sample cell serial numbers 2000 and greater) allows the intake to be removed by the user. Once removed, the inner stainless steel tubing that carries the clean sample air from the vortex may be cleaned. The appropriate cleaning procedure depends on whether the contamination is particulate matter that has collected during dry, dusty conditions, or if it is an accumulation of soluble material such as salt deposits. Instructions on detaching the vortex intake are found in section C.2.1 below, and guidance for cleaning either type of contamination is found in sections C.2.2 and C.2.3, respectively.

The older design of the EC155 intake tube is not designed to be removed by the user. If it becomes dirty, it may be cleaned while attached to the sample cell assembly following the guidelines in sections C.2.2 and C.2.3 below.

C.2.1 Detaching the Vortex Intake

1. Turn off the pump.
2. Power down the analyzer.
3. Remove analyzer from the sample cell.

4. Pull the bypass tube out of the bypass tube connection sleeve.
5. Disconnect the heater cable connection. See FIGURE C-1.
6. Loosen the four screws that secure the intake mounting plate in place and remove the plate. See FIGURE C-1.
7. Locate the black nut next to the stainless steel block of the sample cell that holds the stainless steel sample tubing in place by compressing two rubber o-rings around the tubing. Loosen this nut roughly two full turns but don't remove it. See FIGURE C-1.
8. Carefully pull the intake away from the sample cell, sliding the stainless steel sample tubing from the sample cell. See FIGURE C-2.

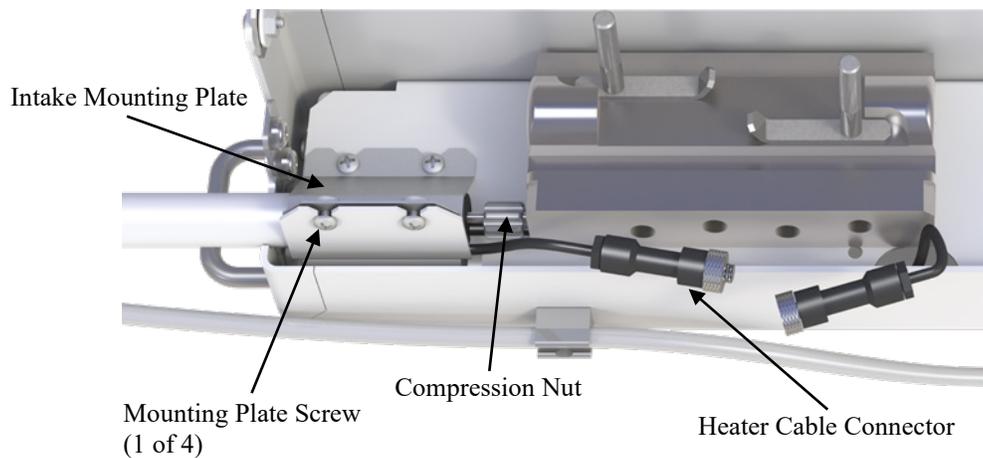


FIGURE C-1. Identification of parts for detaching intake with heater cable shown disconnected

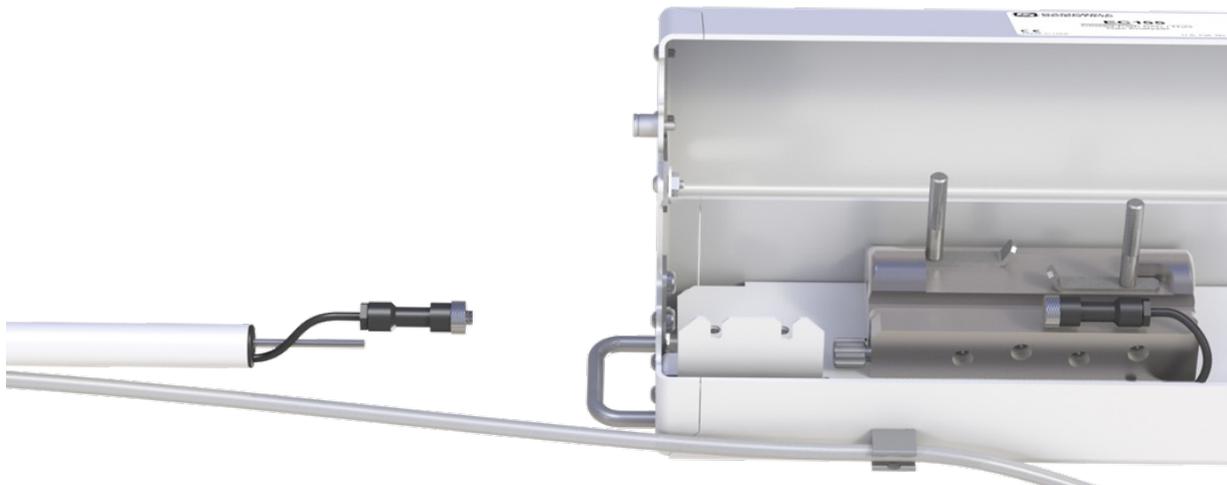


FIGURE C-2. Removal of the vortex intake

After servicing the intake, it should be reattached following the steps above in reverse order.

When reattaching the intake, insert the stainless steel tube back through the small black nut and into the sample cell by pushing directly on the black Santoprene end piece. Push until the end of the stainless steel tubing hits against the sample cell and about 8 mm (0.31 in) of the stainless steel tubing is exposed between the black nut and the black grommet inside the white intake tube. Once fully seated, the end of the large white tube should be within 2 mm of being flush with the edge of the mounting plate. As a final check to ensure the tube has been inserted and sealed properly, the user may direct his or her breath through and small tube directed as the tube insertion point while the analyzer is making measurements. If no CO₂ peak is observed, there is no leak.

CAUTION When reattaching the intake, if the stainless steel tubing is not fully seated against the sample cell, a leak could be introduced.

C.2.2 Dust Blowout

For a vortex intake tube that remains dusty even after performing the air blast procedure described in step 5 of Section 9.2.1.2, *Cleaning the Bypass Tubing and Vortex Chamber* (p. 37), it is recommended to detach the intake as described in the section above and then use compressed air to blow out the intake sample tubing.

For older sample cells (serial numbers less than 2000), if the intake tube is dusty, the cleaning procedure is similar to the air blast procedure for the vortex intake and is described in detail in the steps below.

CAUTION For the older design sample cell, do not blow the dust out of the intake assembly using compressed gas as this may damage the differential pressure sensor in the sample cell assembly. The maximum pressure allowed on the pressure sensor is 75 kPa (differential).

1. Run the system normally, with the analyzer in place and the pump on.
2. Remove the filter at the inlet of the intake.
3. Plug the hole in the inlet with your finger. The pump will pull a vacuum on its internal filter/buffer volume, the pump tube, analyzer, and intake tube.
4. After approximately one minute, unplug the hole.

NOTE During these steps, ambient air will rush in and blow dust from the inner walls of the intake tube, which is likely to be deposited on the analyzer windows. For this reason, Campbell Scientific recommends performing the dust blowout prior to cleaning windows.

5. Repeat this procedure as needed.

When the windows no longer become dirty (CO₂ and H₂O signal levels do not change) this indicates no more dust is being removed from the intake tube.

C.2.3 Solvent Flush

If the intake tube has other contamination, such as salt deposits, it may be flushed with water or alcohol. For the newer design vortex intake, once it is detached, a syringe filled with solvent can flush solvent through the intake sample tubing. Once it has been adequately flushed, fill the syringe with air to push any remaining solvent droplets out of the intake.

NOTE

This procedure is likely to leave some of the solvent in the system. Make sure it is completely dry before attempting a zero/span.

For sample cells of the older design (serial numbers less than 2000), since the intake cannot be detached, care must be exercised to keep the solvent out of the pressure sensor passages (see earlier note on cleaning the sample cell). Following the next steps will help keep the pressure sensor passages clear.

1. Power the system down.
2. Remove the sensor head from the sample cell.
3. Close the lid of the sample cell assembly.
4. Position sample cell assembly upside down. This allows the solvent to flow away from the pressure sensor passage.
5. Tilt slightly so that the intake is higher than the sample cell.
6. Remove the intake filter.
7. Fill a syringe with solvent (generally, tap water will be sufficient) and press it against the hole in the end of the intake tube.
8. Depress the plunger to let the solvent flow through the intake tube. The waste solvent will collect in the lid of the sample cell assembly.
9. Fill the syringe with air and push the air through the intake tube to force most of the solvent out of the tube.
10. Dump the solvent out of the sample cell assembly and wipe the assembly dry.
11. Clean the analyzer windows and the sample cell as described in Section 9.3, *Cleaning Analyzer Windows* (p. 40), and C.1, *Cleaning Sample Cell* (p. c-1), in the section above.

NOTE

This procedure is likely to leave some of the solvent in the system. Make sure it is completely dry before attempting a zero/span.

Appendix D. CSAT3A Orientation

D.1 Determining True North and Sensor Orientation

The orientation of the sonic anemometer negative x-axis is found by reading a magnetic compass and applying the site-specific correction for magnetic declination; where the magnetic declination is the number of degrees between true north and magnetic north. Magnetic declination for a specific site can be obtained from a USGS map, local airport, or through a NOAA web calculator (Appendix D.2, *Online Magnetic Declination Calculator (p. D-2)*). A general map showing magnetic declination for the Conterminous United States in 2015 is shown in FIGURE D-1.

Declination angles east of true north are considered negative, and are subtracted from 360 degrees to get true north as shown in FIGURE D-2. Declination angles west of true north are considered positive and are added to 0° to get true north as shown in FIGURE D-3.

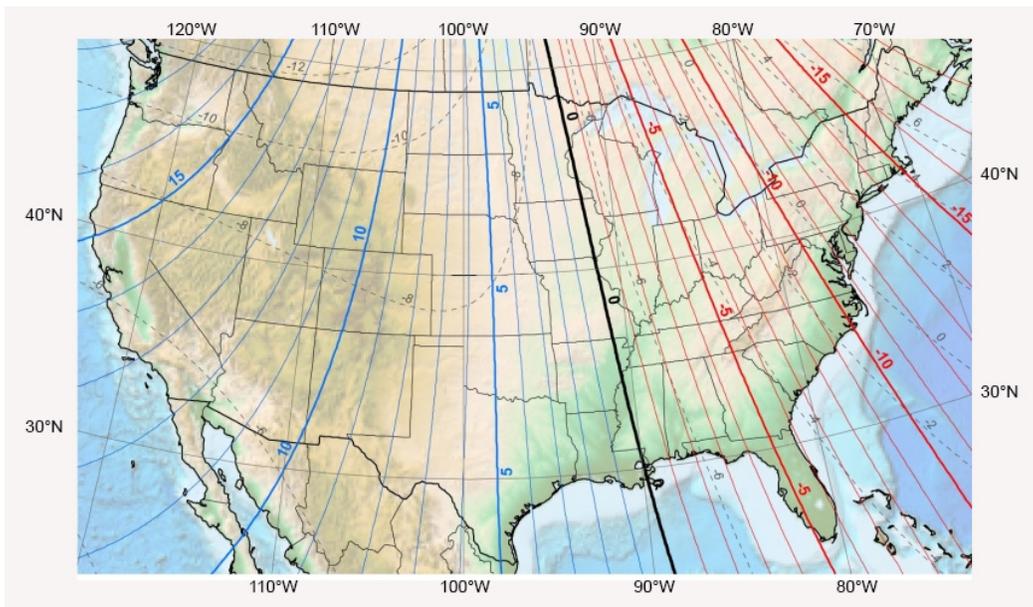


FIGURE D-1. Magnetic declination for the contiguous United States (2015)

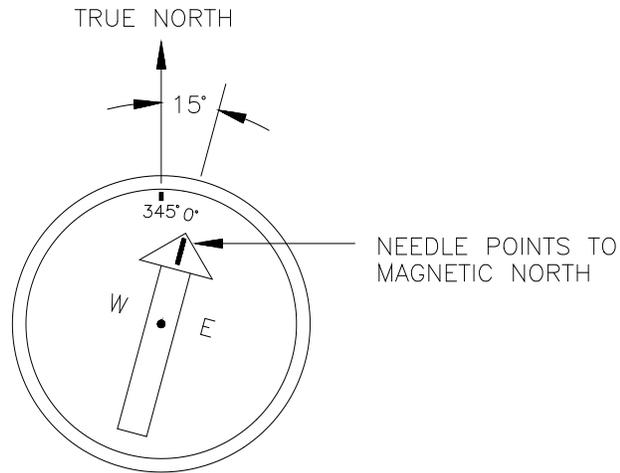


FIGURE D-2. Declination angles east of true north are subtracted from 360 to get true north

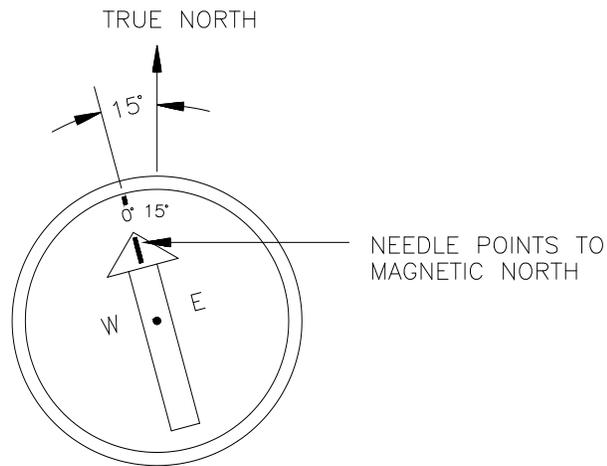


FIGURE D-3. Declination angles west of true north are added to 0 to get true north

D.2 Online Magnetic Declination Calculator

The magnetic declination web calculator published by NOAA’s Geophysical Data Center is available at the following URL:

<https://www.ngdc.noaa.gov/geomag-web/#declination>. Enter the latitude, longitude, date, and the format you wish to view the data. Once entered, click “calculate” to determine the declination (FIGURE D-4).

NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA > NESDIS > NCEI (formerly NGDC) > Geomagnetism

Magnetic Field Calculators

Declination U.S. Historic Declination Magnetic Field Magnetic Field Component Grid

Magnetic Declination Estimated Value

Declination is calculated using the most recent [World Magnetic Model \(WMM\)](#) or the [International Geomagnetic Reference Field \(IGRF\)](#) model. For 1590 to 1900 the calculator is based on the [gufm1](#) model. A smooth transition from gufm1 to IGRF was imposed from 1990 to 1995. Declination results are typically accurate to 30 minutes of arc, but environmental factors can cause magnetic field disturbances. Results can be downloaded in HTML, XML, or CSV programmatically (API). For more information click the information link.

Calculate Declination

Latitude: S N

Longitude: W E

Model: WMM (2014-2019) IGRF (1590-2019)

Date: Year Month Day

Result format: HTML XML CSV PDF

Declination

Model Used: WMM2015

Latitude: 41.7640593° N

Longitude: 111.8573484° W

Date	Declination
2018-11-09	11.47° E ± 0.36° changing by 0.11° W per year

NOAA > NESDIS > NCEI (formerly NGDC) > Geomagnetism

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FIGURE D-4. Online magnetic declination calculator with inputs and output for Logan, UT

The declination for Logan, UT is 11.47° E. Therefore, true north is $360^\circ - 11.47^\circ = 348.53^\circ$. So when looking at a compass at this location, true north is located at 348.53°, not 360°. Declination results are typically accurate to 30 minutes of arc, but environmental factors can cause magnetic field disturbances.

Appendix E. Safety Data Sheets (SDS)

E.1 Molecular Sieve, Type 13X



Safety Data Sheet
per OSHA HazCom 2012

Page 1/4
Printing date 11/24/2015
Reviewed on 02/24/2012

1 Identification

Product identifier

Product name: Molecular sieve, Type 13X

Stock number: A10378

CAS Number:

63231-69-6

Relevant identified uses of the substance or mixture and uses advised against.

Identified use: SU24 Scientific research and development

Details of the supplier of the safety data sheet

Manufacturer/Supplier:

Alfa Aesar
Thermo Fisher Scientific Chemicals, Inc.
30 Bond Street
Ward Hill, MA 01835-8099
Tel: 800-343-0660
Fax: 800-322-4757
Email: tech@alfa.com
www.alfa.com

Information Department: Health, Safety and Environmental Department

Emergency telephone number:

During normal business hours (Monday-Friday, 8am-7pm EST), call (800) 343-0660. After normal business hours, call Carechem 24 at (866) 928-0789.

2 Hazard(s) identification

Classification of the substance or mixture in accordance with 29 CFR 1910 (OSHA HCS)

The substance is not classified according to the Globally Harmonized System (GHS).

Hazards not otherwise classified: No information known.

Label elements

GHS label elements: Not applicable

Hazard pictograms: Not applicable

Signal word: Not applicable

Hazard statements: Not applicable

WHMIS classification: Not controlled

Classification system

HMS ratings (scale 0-4)

(Hazardous Materials Identification System)

HEALTH	1	Health (acute effects) = 1
FIRE	0	Flammability = 0
REACTIVITY	0	Physical Hazard = 0

Other hazards:

Results of PBT and vPvB assessment

PBT: Not applicable.

vPvB: Not applicable.

3 Composition/information on ingredients

Chemical characterization: Substances

CAS# Description:

63231-69-6 Molecular sieve, Type 13x

4 First-aid measures

Description of first aid measures

After inhalation

Supply fresh air. If required, provide artificial respiration. Keep patient warm.

Seek immediate medical advice.

After skin contact

Immediately wash with water and soap and rinse thoroughly.

Seek immediate medical advice.

After eye contact: Rinse opened eye for several minutes under running water. Then consult a doctor.

After swallowing: Seek medical treatment.

Information for doctor

Most important symptoms and effects, both acute and delayed: No further relevant information available.

Indication of any immediate medical attention and special treatment needed: No further relevant information available.

5 Fire-fighting measures

Extinguishing media

Suitable extinguishing agents: Product is not flammable. Use fire-fighting measures that suit the surrounding fire.

Special hazards arising from the substance or mixture

If this product is involved in a fire, the following can be released:

Metal oxide fume

Silicon oxide

Sodium oxide

Advice for firefighters

Protective equipment:

Wear self-contained respirator.

Wear fully protective impervious suit.

6 Accidental release measures

Personal precautions, protective equipment and emergency procedures

Wear protective equipment. Keep unprotected persons away.

Ensure adequate ventilation.

Environmental precautions: Do not allow material to be released to the environment without proper governmental permits.

Methods and material for containment and cleaning up: Pick up mechanically.

Prevention of secondary hazards: No special measures required.

Reference to other sections

See Section 7 for information on safe handling.

(Cont'd. on page 2)
USA

Safety Data Sheet
per OSHA HazCom 2012

Page 2/4
Printing date 11/24/2015
Reviewed on 02/24/2012

Product name: Molecular sieve, Type 13X

See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.

(Contd. of page 1)

7 Handling and storage

Handling
Precautions for safe handling
Keep container tightly sealed.
Store in cool, dry place in tightly closed containers.
Information about protection against explosions and fires: The product is not flammable
Conditions for safe storage, including any incompatibilities
Storage
Requirements to be met by storerooms and receptacles: No special requirements.
Information about storage in one common storage facility: No information known.
Further information about storage conditions:
Keep container tightly sealed.
Store in cool, dry conditions in well sealed containers.
Specific end use(s) No further relevant information available.

8 Exposure controls/personal protection

Additional information about design of technical systems:
Properly operating chemical fume hood designed for hazardous chemicals and having an average face velocity of at least 100 feet per minute.
Control parameters
Components with limit values that require monitoring at the workplace:
The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.
Additional information: No data
Exposure controls
Personal protective equipment
General protective and hygienic measures
The usual precautionary measures for handling chemicals should be followed.
Keep away from foodstuffs, beverages and feed.
Remove all soiled and contaminated clothing immediately.
Wash hands before breaks and at the end of work.
Maintain an ergonomically appropriate working environment.
Breathing equipment: Use suitable respirator when high concentrations are present.
Protection of hands:
Imperious gloves
Check protective gloves prior to each use for their proper condition.
The selection of suitable gloves not only depends on the material, but also on quality. Quality will vary from manufacturer to manufacturer.
Penetration time of glove material (in minutes) Not determined
Eye protection: Safety glasses
Body protection: Protective work clothing.

9 Physical and chemical properties

Information on basic physical and chemical properties

General Information

Appearance:

Form:	Powder/crystalline/beads
Color:	Light brown
Odor:	Odorless
Odor threshold:	Not determined.

pH-value: Not applicable.

Change in condition

Melting point/Melting range:	Not determined
Boiling point/Boiling range:	Not determined
Sublimation temperature / start:	Not determined
Flammability (solid, gaseous)	Not determined.
Ignition temperature:	Not determined
Decomposition temperature:	Not determined
Auto igniting:	Not determined.

Danger of explosion: Not determined.

Explosion limits:

Lower:	Not determined
Upper:	Not determined
Vapor pressure:	Not applicable.
Density at 20 °C (68 °F):	1,1 g/cm ³ (9,18 lbs/gal)
Relative density	Not determined.
Vapor density	Not applicable.
Evaporation rate	Not applicable.

Solubility in / Miscibility with

Water:	Insoluble
Partition coefficient (n-octanol/water):	Not determined.

Viscosity:

dynamic:	Not applicable.
kinematic:	Not applicable.

Other information No further relevant information available.

10 Stability and reactivity

Reactivity No information known.
Chemical stability Stable under recommended storage conditions.
Thermal decomposition / conditions to be avoided: Decomposition will not occur if used and stored according to specifications.
Possibility of hazardous reactions No dangerous reactions known
Conditions to avoid No further relevant information available.
Incompatible materials: No information known.
Hazardous decomposition products:
Metal oxide fume
Silicon oxide

(Contd. on page 3)
USA

Safety Data Sheet
per OSHA HazCom 2012

Page 3/4
Printing date 11/24/2015
Reviewed on 02/24/2012

Product name: **Molecular sieve, Type 13X**

Sodium oxide

(Contd. of page 2)

11 Toxicological information

Information on toxicological effects

Acute toxicity: No effects known.
LD/LC50 values that are relevant for classification: No data
Skin irritation or corrosion: May cause irritation
Eye irritation or corrosion: May cause irritation
Sensitization: No sensitizing effects known.
Germ cell mutagenicity: No effects known.
Carcinogenicity: No classification data on carcinogenic properties of this material is available from the EPA, IARC, NTP, OSHA or ACGIH.
Reproductive toxicity: No effects known.
Specific target organ system toxicity - repeated exposure: No effects known.
Specific target organ system toxicity - single exposure: No effects known.
Aspiration hazard: No effects known.
Subacute to chronic toxicity: No effects known.
Additional toxicological information: To the best of our knowledge the acute and chronic toxicity of this substance is not fully known.

12 Ecological information

Toxicity

Aquatic toxicity: No further relevant information available.
Persistence and degradability: No further relevant information available.
Bioaccumulative potential: No further relevant information available.
Mobility in soil: No further relevant information available.

Additional ecological information:

General notes:
Do not allow material to be released to the environment without proper governmental permits.
Avoid transfer into the environment.
Results of PBT and vPvB assessment
PBT: Not applicable.
vPvB: Not applicable.
Other adverse effects: No further relevant information available.

13 Disposal considerations

Waste treatment methods
Recommendation: Consult state, local or national regulations to ensure proper disposal.
Uncleaned packagings:
Recommendation: Disposal must be made according to official regulations.

14 Transport information

UN-Number
DOT, ADN, IMDG, IATA Not applicable

UN proper shipping name
DOT, ADN, IMDG, IATA Not applicable

Transport hazard class(es)
DOT, ADR, ADN, IMDG, IATA
Class Not applicable

Packing group
DOT, IMDG, IATA Not applicable

Environmental hazards: Not applicable.

Special precautions for user Not applicable.

Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code Not applicable.

Transport/Additional information:

DOT

Marine Pollutant (DOT): No

UN "Model Regulation": -

15 Regulatory information

Safety, health and environmental regulations/legislation specific for the substance or mixture

GHS label elements: Not applicable

Hazard pictograms: Not applicable

Signal word: Not applicable

Hazard statements: Not applicable

National regulations

This product is not listed in the U.S. Environmental Protection Agency Toxic Substances Control Act Chemical Substance Inventory. Use of this product is restricted to research and development only. This product must be used by or directly under the supervision of a technically qualified individual as defined by TSCA. This product must not be used for commercial purposes or in formulations for commercial purposes.

SARA Section 313 (specific toxic chemical listings): Substance is not listed.

California Proposition 65

Prop 65 - Chemicals known to cause cancer: Substance is not listed.

Prop 65 - Developmental toxicity: Substance is not listed.

Prop 65 - Developmental toxicity, female: Substance is not listed.

Prop 65 - Developmental toxicity, male: Substance is not listed.

Information about limitation of use: For use only by technically qualified individuals.

Other regulations, limitations and prohibitive regulations

Substance of Very High Concern (SVHC) according to the REACH Regulations (EC) No. 1907/2006: Substance is not listed.

The conditions of restrictions according to Article 67 and Annex XVII of the Regulation (EC) No 1907/2006 (REACH) for the manufacturing, placing on the market and use must be observed.

Substance is not listed.

Annex XIV of the REACH Regulations (requiring Authorisation for use): Substance is not listed.

Chemical safety assessment: A Chemical Safety Assessment has not been carried out.

USA

(Contd. on page 4)

Safety Data Sheet
per OSHA HazCom 2012

Page 4/4
Printing date 11/24/2015
Reviewed on 02/24/2012

Product name: Molecular sieve, Type 13X

(Contd. of page 3)

16 Other information

Employers should use this information only as a supplement to other information gathered by them, and should make independent judgement of suitability of this information to ensure proper use and protect the health and safety of employees. This information is furnished without warranty, and any use of the product not in conformance with this Material Safety Data Sheet, or in combination with any other product or process, is the responsibility of the user.

Department issuing SDS: Global Marketing Department

Date of preparation / last revision 11/24/2015 / -

Abbreviations and acronyms:

RII: Règlement international concernant le transport des marchandises dangereuses par chemin de fer (Regulations Concerning the International Transport of Dangerous Goods by Rail)
ICAO: International Civil Aviation Organization
ADR: Accord européen sur le transport des marchandises dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)
IMDG: International Maritime Code for Dangerous Goods
DOT: US Department of Transportation
ATA: International Air Transport Association
CAS: Chemical Abstracts Service (division of the American Chemical Society)
HMIS: Hazardous Materials Identification System (USA)
WHMIS: Workplace Hazardous Materials Information System (Canada)
LC50: Lethal concentration, 50 percent
LD50: Lethal dose, 50 percent
vPvD: very Persistent and very Bioaccumulative
ACGIH: American Conference of Governmental Industrial Hygienists (USA)
OSHA: Occupational Safety and Health Administration (USA)
NTP: National Toxicology Program (USA)
IARC: International Agency for Research on Cancer
EPA: Environmental Protection Agency (USA)

USA

E.2 Magnesium Perchlorate



SAFETY DATA SHEET

1. Identification

Product identifier	MAGNESIUM PERCHLORATE, ANHYDROUS, REAGENT (ACS)	
Other means of identification		
Product code	55	
Recommended use	professional, scientific and technical activities: scientific research and development	
Recommended restrictions	None known.	
Manufacturer/Importer/Supplier/Distributor information		
Company name	GFS Chemicals, Inc.	
Address	P.O. Box 245 Powell OH 43065 US	
Telephone	Phone	740-881-5501
	Toll Free	800-858-9682
	Fax	740-881-5989
Website	www.gfschemicals.com	
E-mail	service@gfschemicals.com	
Emergency phone number	Emergency Assistance	Chemtrec 800-424-9300

2. Hazard(s) identification

Physical hazards	Oxidizing solids	Category 2
Health hazards	Serious eye damage/eye irritation	Category 2A
	Specific target organ toxicity, single exposure	Category 3 respiratory tract irritation
OSHA hazard(s)	Not classified.	
Label elements		



Signal word	Danger
Hazard statement	May intensify fire; oxidizer. Causes serious eye irritation. May cause respiratory irritation.
Precautionary statement	
Prevention	Keep/Store away from clothing and other combustible materials. Keep away from heat. Use only outdoors or in a well-ventilated area. Take any precaution to avoid mixing with combustibles. Avoid breathing dust. Wash thoroughly after handling. Wear protective gloves/eye protection/face protection.
Response	If inhaled: Remove person to fresh air and keep comfortable for breathing. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Call a POISON CENTER or doctor/physician if you feel unwell. If eye irritation persists: Get medical advice/attention. In case of fire: Use appropriate media for extinction.
Storage	Store in a well-ventilated place. Keep container tightly closed. Store locked up.
Disposal	Dispose of contents/container to an appropriate treatment and disposal facility in accordance with applicable laws and regulations, and product characteristics at time of disposal.
Hazard(s) not otherwise classified (HNOC)	Not classified.

3. Composition/information on ingredients

Substances

Hazardous components			
Chemical name	Common name and synonyms	CAS number	%
MAGNESIUM PERCHLORATE		10034-81-8	100

Material name: MAGNESIUM PERCHLORATE, ANHYDROUS, REAGENT (ACS)

55

Version #: 01

Revision date: Issue date: March-26-2013

SDS US

1 / 7

*Designates that a specific chemical identity and/or percentage of composition has been withheld as a trade secret.

4. First-aid measures

Inhalation	If dust from the material is inhaled, remove the affected person immediately to fresh air. Call a POISON CENTER or doctor/physician if you feel unwell.
Skin contact	Immediately flush skin with plenty of water. Get medical attention if irritation develops and persists.
Eye contact	Immediately flush eyes with plenty of water for at least 15 minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical advice/attention.
Ingestion	Have victim rinse mouth thoroughly with water. Drink 1 or 2 glasses of water.
Most important symptoms/effects, acute and delayed	Irritation of eyes and mucous membranes.
Indication of immediate medical attention and special treatment needed	Provide general supportive measures and treat symptomatically.
General information	Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves.

5. Fire-fighting measures

Suitable extinguishing media	Water.
Unsuitable extinguishing media	None known.
Specific hazards arising from the chemical	May intensify fire; oxidizer.
Special protective equipment and precautions for firefighters	Firefighters must use standard protective equipment including flame retardant coat, helmet with face shield, gloves, rubber boots, and in enclosed spaces, SCBA.
Fire-fighting equipment/instructions	Move containers from fire area if you can do it without risk. Move containers from fire area if you can do so without risk. In the event of fire, cool tanks with water spray. For massive fire in cargo area, use unmanned hose holder or monitor nozzles, if possible. If not, withdraw and let fire burn out.
Specific methods	Cool containers exposed to flames with water until well after the fire is out.

6. Accidental release measures

Personal precautions, protective equipment and emergency procedures	Keep unnecessary personnel away. Local authorities should be advised if significant spillages cannot be contained. Use a NIOSH/MSHA approved respirator if there is a risk of exposure to dust/fume at levels exceeding the exposure limits. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Keep people away from and upwind of spill/leak. Keep upwind. Keep out of low areas. Ventilate closed spaces before entering them. Avoid inhalation of dust from the spilled material. Wear appropriate personal protective equipment.
Methods and materials for containment and cleaning up	ELIMINATE all ignition sources (no smoking, flares, sparks or flames in immediate area). Keep combustibles (wood, paper, oil, etc.) away from spilled material. This product is miscible in water. After removal flush contaminated area thoroughly with water. If sweeping of a contaminated area is necessary use a dust suppressant agent which does not react with the product. Sweep up or vacuum up spillage and collect in suitable container for disposal. Collect dust using a vacuum cleaner equipped with HEPA filter. Avoid the generation of dusts during clean-up. Dilute with plenty of water. Following product recovery, flush area with water. Prevent entry into waterways, sewer, basements or confined areas. For waste disposal, see section 13 of the MSDS.
Environmental precautions	Avoid discharge into drains, water courses or onto the ground. Prevent further leakage or spillage if safe to do so.

7. Handling and storage

Precautions for safe handling	Avoid dust formation. Do not breathe dust from this material. In case of insufficient ventilation, wear suitable respiratory equipment. Take any precaution to avoid mixing with combustibles. Keep away from heat. Guard against dust accumulation of this material. Provide appropriate exhaust ventilation at places where dust is formed. Avoid contact with skin and eyes. Wash hands thoroughly after handling. Practice good housekeeping.
Conditions for safe storage, including any incompatibilities	Do not store around flammable or combustible materials. Keep away from heat. Store in a well-ventilated place. Keep container tightly closed. Avoid dust formation. Do not store near combustible materials. Guard against dust accumulation of this material. Keep out of the reach of children. Store in a cool, dry place out of direct sunlight.

8. Exposure controls/personal protection

Occupational exposure limits	No exposure limits noted for ingredient(s).
Biological limit values	No biological exposure limits noted for the ingredient(s).
Appropriate engineering controls	Ventilation should be sufficient to effectively remove and prevent buildup of any dusts or fumes that may be generated during handling or thermal processing. An eye wash and safety shower must be available in the immediate work area.
Individual protection measures, such as personal protective equipment	
Eye/face protection	Wear eye/face protection. Use tight fitting goggles if dust is generated. Eye wash fountains are required.
Skin protection	
Hand protection	Wear protective gloves.
Other	Wear suitable protective clothing. Wear protective gloves.
Respiratory protection	Respirator must be worn if exposed to dust. Wear respirator with dust filter.
Thermal hazards	Not available.
General hygiene considerations	Do not breathe dust. Avoid contact with eyes. Wash hands before breaks and immediately after handling the product. Handle in accordance with good industrial hygiene and safety practice.

9. Physical and chemical properties

Appearance	Granular. and Powder.
Physical state	Solid.
Form	Solid.
Color	White.
Odor	Odorless.
Odor threshold	Not available.
pH	Not available.
Melting point/freezing point	482 °F (250 °C)
Initial boiling point and boiling range	Not available.
Flash point	Not available.
Evaporation rate	Not available.
Flammability (solid, gas)	Not applicable.
Upper/lower flammability or explosive limits	
Flammability limit - lower (%)	Not available.
Flammability limit - upper (%)	Not available.
Explosive limit - lower (%)	Not available.
Explosive limit - upper (%)	Not available.
Vapor pressure	Not available.
Vapor density	Not available.
Relative density	Not available.
Solubility(ies)	Very soluble with evolution of heat
Partition coefficient (n-octanol/water)	Not available.
Auto-ignition temperature	Not available.
Decomposition temperature	> 482 °F (> 250 °C) When heated to decomp, emits toxic fumes of magnesium oxide and hydrogen chloride.
Viscosity	Not available.
Other information	
Density	2.20 g/cm ³ estimated
Molecular formula	Mg(ClO ₄) ₂
Molecular weight	223.23 g/mol
pH in aqueous solution	5 - 8 (5% solution)

Material name: MAGNESIUM PERCHLORATE, ANHYDROUS, REAGENT (ACS)

SDS US

55

Version #: 01

Revision date: Issue date: March-26-2013

3 / 7

Specific gravity 2.2

10. Stability and reactivity

Reactivity	Combustible material.
Chemical stability	Material is stable under normal conditions. Risk of ignition.
Possibility of hazardous reactions	Hazardous polymerization does not occur.
Conditions to avoid	Avoid spread of dust. Drying of this product on clothing or combustible materials may cause fire. Excessive heat.
Incompatible materials	Exothermic reaction on contact with water will release heat and steam. Organic materials Strong acids.
Hazardous decomposition products	Hydrogen chloride.

11. Toxicological information

Information on likely routes of exposure

Ingestion	Due to lack of data the classification is not possible.
Inhalation	Inhalation of dusts may cause respiratory irritation.
Skin contact	Due to lack of data the classification is not possible.
Eye contact	Causes serious eye irritation.

Symptoms related to the physical, chemical and toxicological characteristics Not available.

Information on toxicological effects

Acute toxicity

Product	Species	Test Results
MAGNESIUM PERCHLORATE (CAS 10034-81-8)		
Acute		
<i>Other</i>		
LD50	Mouse	1500 mg/kg

* Estimates for product may be based on additional component data not shown.

Skin corrosion/irritation	Due to lack of data the classification is not possible.
Serious eye damage/eye irritation	Causes serious eye irritation. Dust in the eyes will cause irritation.
Respiratory sensitization	Due to lack of data the classification is not possible.
Skin sensitization	Due to lack of data the classification is not possible.
Germ cell mutagenicity	Due to lack of data the classification is not possible.
Carcinogenicity	This product is not considered to be a carcinogen by IARC, ACGIH, NTP, or OSHA.
Reproductive toxicity	Due to lack of data the classification is not possible.
Specific target organ toxicity - single exposure	Respiratory tract irritation.
Specific target organ toxicity - repeated exposure	The perchlorate ion competes with iodide in the mechanism that governs uptake into the thyroid gland for growth hormone production. This effect is routinely countered by ensuring sufficient dietary intake of iodine, as perchlorate does not accumulate in the body. Studies on workers in plants where perchlorates are manufactured have shown no thyroid abnormalities; various clinical studies are ongoing. Perchlorates occur naturally in trace amounts in the environment, and are not classified as carcinogenic. Due to lack of data the classification is not possible.
Aspiration hazard	Due to lack of data the classification is not possible.
Further information	This product has no known adverse effect on human health.

12. Ecological information

Ecotoxicity	This material is not expected to be harmful to aquatic life.
Persistence and degradability	None known.
Bioaccumulative potential	Not available.
Mobility in soil	Not available.
Other adverse effects	Not available.

Material name: MAGNESIUM PERCHLORATE, ANHYDROUS, REAGENT (ACS)

55

Version #: 01

Revision date: Issue date: March-26-2013

SDS US

4 / 7

13. Disposal considerations

Disposal instructions	Collect and reclaim or dispose in sealed containers at licensed waste disposal site. This material and its container must be disposed of as hazardous waste. Do not allow this material to drain into sewers/water supplies. Do not contaminate ponds, waterways or ditches with chemical or used container. If discarded, this product is considered a RCRA ignitable waste, D001. Dispose of contents/container in accordance with local/regional/national/international regulations.
Local disposal regulations	Not available.
Hazardous waste code	D001: Waste Flammable material with a flash point <140 F
Waste from residues / unused products	Dispose of in accordance with local regulations. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions). Not applicable.
Contaminated packaging	Empty containers should be taken to an approved waste handling site for recycling or disposal. Since emptied containers may retain product residue, follow label warnings even after container is emptied. Offer rinsed packaging material to local recycling facilities.

14. Transport information**DOT**

UN number	UN1475
UN proper shipping name	Magnesium perchlorate
Transport hazard class(es)	5.1
Subsidiary class(es)	Not available.
Packing group	II
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Labels required	5.1
Special provisions	IB6, IP2, T3, TP33
Packaging exceptions	152
Packaging non bulk	212
Packaging bulk	242

IATA

UN number	UN1475
UN proper shipping name	Magnesium perchlorate
Transport hazard class(es)	5.1
Subsidiary class(es)	-
Packaging group	II
Environmental hazards	No
Labels required	Not available.
ERG Code	5L
Special precautions for user	Not available.

IMDG

UN number	UN1475
UN proper shipping name	MAGNESIUM PERCHLORATE
Transport hazard class(es)	5.1
Subsidiary class(es)	-
Packaging group	II
Environmental hazards	
Marine pollutant	No
Labels required	Not available.
EmS	F-H, S-Q
Special precautions for user	Not available.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code No information available.

DOT



IATA; IMDG



15. Regulatory information

US federal regulations

This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

CERCLA/SARA Hazardous Substances - Not applicable.

All components are on the U.S. EPA TSCA Inventory List.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

US. OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not on regulatory list.

CERCLA Hazardous Substance List (40 CFR 302.4)

Not listed.

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories

Immediate Hazard - Yes
 Delayed Hazard - Yes
 Fire Hazard - Yes
 Pressure Hazard - No
 Reactivity Hazard - No

SARA 302 Extremely hazardous substance

No

SARA 311/312

No

Hazardous chemical

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Not regulated.

Safe Drinking Water Act (SDWA)

Not regulated.

Drug Enforcement Administration (DEA). List 2, Essential Chemicals (21 CFR 1310.02(b) and 1310.04(f)(2) and Chemical Code Number

Not listed.

Drug Enforcement Administration (DEA). List 1 & 2 Exempt Chemical Mixtures (21 CFR 1310.12(c))

Not regulated.

DEA Exempt Chemical Mixtures Code Number

Not regulated.

Food and Drug Administration (FDA)

Not regulated.

US state regulations

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

Material name: MAGNESIUM PERCHLORATE, ANHYDROUS, REAGENT (ACS)

55

Version #: 01

Revision date: Issue date: March-26-2013

SDS US

6 / 7

US. Massachusetts RTK - Substance List

MAGNESIUM PERCHLORATE (CAS 10034-81-8)

US. New Jersey Worker and Community Right-to-Know Act

Not regulated.

US. Pennsylvania RTK - Hazardous Substances

MAGNESIUM PERCHLORATE (CAS 10034-81-8)

US. Rhode Island RTK

MAGNESIUM PERCHLORATE (CAS 10034-81-8)

US. California Proposition 65**US - California Proposition 65 - Carcinogens & Reproductive Toxicity (CRT): Listed substance**

Not listed.

International Inventories

Country(s) or region	Inventory name	On inventory (yes/no)*
Australia	Australian Inventory of Chemical Substances (AICS)	Yes
Canada	Domestic Substances List (DSL)	Yes
Canada	Non-Domestic Substances List (NDSL)	No
China	Inventory of Existing Chemical Substances in China (IECSC)	Yes
Europe	European Inventory of Existing Commercial Chemical Substances (EINECS)	Yes
Europe	European List of Notified Chemical Substances (ELINCS)	No
Japan	Inventory of Existing and New Chemical Substances (ENCS)	Yes
Korea	Existing Chemicals List (ECL)	Yes
New Zealand	New Zealand Inventory	Yes
Philippines	Philippine Inventory of Chemicals and Chemical Substances (PICCS)	Yes
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s)

16. Other information, including date of preparation or last revision**Issue date** March-26-2013**Version #** 01**Further information** Not available.

Disclaimer The information in the sheet was written based on the best knowledge and experience currently available. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

Revision Information Product and Company Identification: Alternate Trade Names
 Hazards Identification: US Hazardous
 Composition / Information on Ingredients: Ingredients
 Physical & Chemical Properties: Multiple Properties
 Transport Information: Proper Shipping Name/Packing Group
 Regulatory Information: United States
 HazReg Data: International Inventories

E.3 Decarbite

P. W. PERKINS CO., INC.

221 Commissioners Pike – Woodstown, NJ 08098-2032 USA
1-(856) 769-3525 Fax 1-(856) 769-2177

www.decarbite.com
www.pwperkins.com
pwpc@mindspring.com

SAFETY DATA SHEET

IDENTITY	DECARBITE®
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SECTION I - Identification

PRODUCT CODE: DECS120, DECS121, DECS135, DECB122, DECB123, DECB135

MANUFACTURER'S NAME:

P. W. PERKINS CO., INC.
221 COMMISSIONERS PIKE
WOODSTOWN NJ 08098-2032 USA
856-769-3525

EMERGENCY TELEPHONE NUMBER: 1-800-424-9300 (CHEMTREC)
(INTERNATIONAL: CALL CHEMTREC COLLECT 1-703-527-3887)

DATE PREPARED: JANUARY 5, 2015

SECTION II – Hazards Identification

Route(s) of Entry: Inhalation? 4-Extreme
Skin? 4-Extreme
Ingestion? 3-Severe

Health Hazards (Acute and Chronic): Corrosive to all body tissue which it comes in contact. The chronic local effect may consist of multiple areas of superficial destruction of the skin. Inhalation of dust may cause varying degrees of irritation.

Carcinogenicity: NTP? NA; IARC Monographs? NA;
OSHA Regulated? NA Not listed as a carcinogen.

Signs and Symptoms of Exposure: Itching, burning of skin or eyes. Temporary discomfort of breathing passages.

Medical Conditions Generally Aggravated by Exposure: Increased susceptibility to respiratory illness.

Emergency and First Aid Procedures: Flush with water. Seek medical attention. Eyes – flush with large amounts of clean water, followed by boric acid eye wash solution.

SECTION III – Composition/Information on Ingredients

Proprietary formulation indicating CO₂ Adsorbent
Sodium Hydroxide: CAS #1310-73-2; 90 – 95%
Non Fibrous Silicate: CAS #1318-00-9; 5 – 10%

SECTION IV – FIRST AID MEASURES

Inhalation: Supply fresh air. If not breathing, give artificial respiration.

Ingestion: If swallowed, call for doctor immediately. Drink plenty of water and provide fresh air.

Skin contact: Immediately flush skin with plenty of water and soap. Immediately remove any clothing soiled by the product. Wash clothing before reuse.

Eye Contact: Immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention immediately.

SECTION V – Fire and Explosion Hazard Data

Flash Point (Method Used): No flash to 550° F ASTM D-56

Flammable Limits: Non flammable

LEL: NA

UEL: NA

Extinguishing Media: Product not combustible. Foam/CO₂ or dry chemical can be used. Direct contact with water can cause a violent exothermic reaction.

Special Fire Fighting Procedures: Protective clothing/self contained breathing apparatus should be worn by fire fighters in area where product is stored.

Unusual Fire and Explosion Hazards: Material is stable (non explosive), nonflammable. Will react with varying degrees of intensity on exposure to water and strong acids.

SECTION VI – Accidental Release Measures

Person-related safety precautions: Wear protective equipment. Keep unprotected persons away.

Measures for environmental protections: Do not allow product to reach sewage systems or any water course. Inform authorities in case of seepage into water course or sewage system.

Measures for cleaning/collecting: Use neutralizing agent. Ensure adequate ventilation. Do not flush with water or aqueous cleansing agents.

SECTION VII – Precautions for Safe Handling and Use

Steps to Be Taken in Case Material is Released or Spilled: Wash area with 1 molar Hydrochloric Acid or use caustic spill kit. Wash with clean water.

Waste Disposal Method: Appropriate disposal should conform with local and state health regulations.

Precautions to Be Taken in Handling and Storing: Wear protective clothing, use adequate ventilation where dust may be generated.

Other Precautions: Respirator, eye protection, gloves, lab coat or other clothing to cover exposed skin area.

SECTION XII – Ecological Information

Do not empty into drains. Do not allow undiluted product or large quantities to reach ground water, water course, or sewage system.

SECTION XIII – Disposal Considerations

Review federal, state, and local government requirements prior to disposal. Whatever cannot be saved for recovery or recycling should be managed in an appropriate waste facility. Dispose of container and unused contents in accordance with federal, state, and local requirements.

SECTION XIV – Transport Information**Domestic (Land, DOT)**

DOT Shipping name: Sodium Hydroxide, Solid

DOT ID: UN1823

DOT Hazard Class: 8, corrosive, Packaging Group II

IATA

IATA Shipping name: Sodium Hydroxide, Solid

IATA ID: UN1823

IATA Hazard Class: 8, corrosive, Packaging Group II

IATA Instructions – Passenger/cargo - 859, LTD QTY - 844, Cargo only - 863

SECTION XV– Regulatory Information

HMIS HAZARD RATINGS: Health Hazard 3; Fire Hazard, 0; Reactivity 2

WHMIS Classification: Class E, Corrosive Material

TSCA: On Toxic Substance Control Inventory

Hazardous Substance: RQ 1000 lbs

SARA TITLE III, 311/312: Acute, Reactive

RCRA: Not Regulated

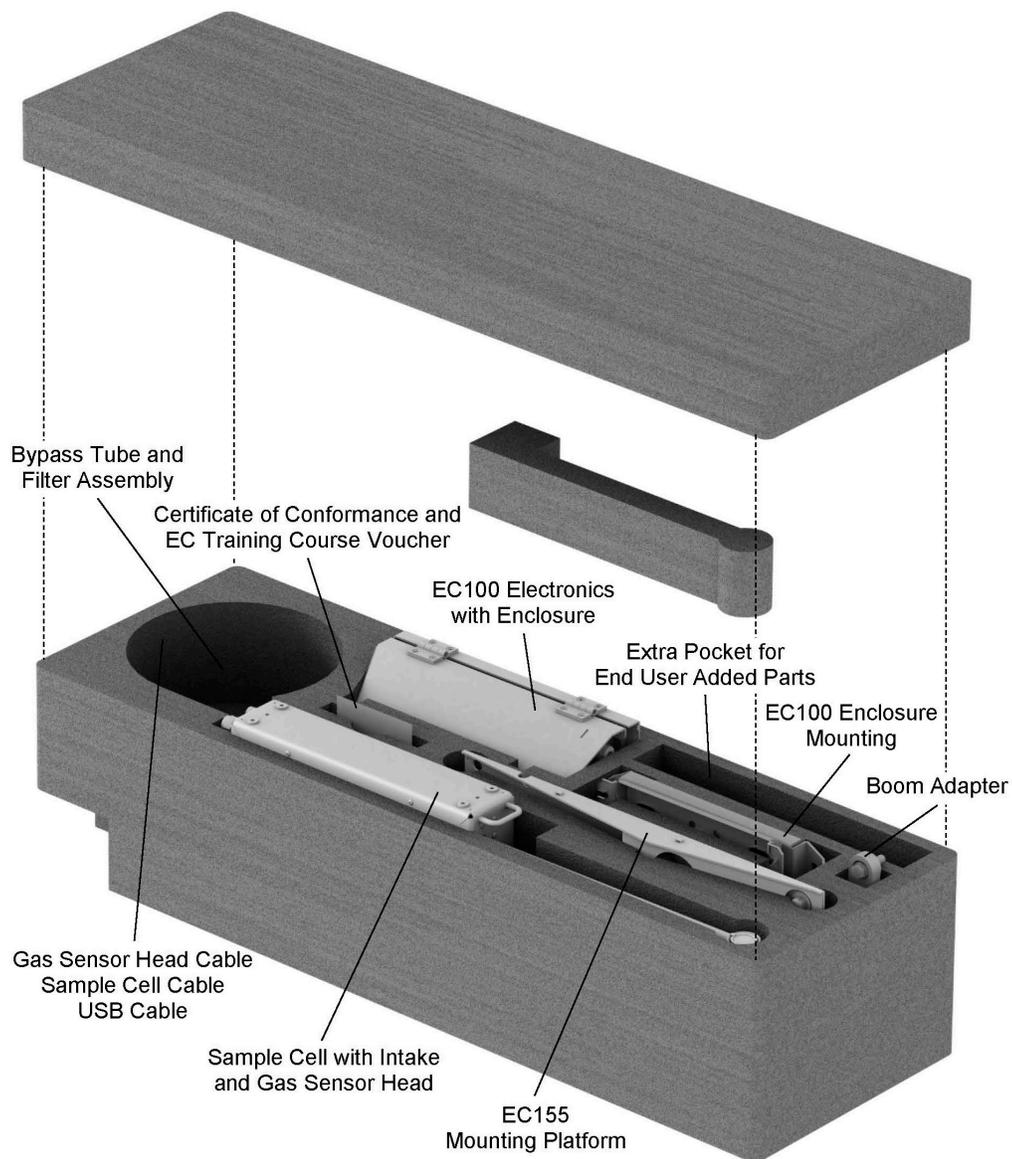
SECTION XVI – Date of Preparation

DATE PREPARED: JANUARY 5, 2015

Appendix F. EC155 Packing Information

The EC155 components are placed in a foam cutout that helps protect them from damage during shipment. The EC155 should look like the following image. After unpacking, it is recommended to save the foam cutout as the EC155 components should be placed in the foam cutout whenever the EC155 is transported to another location.

Note: Another box containing the Sonic Head and its components will also be shipped with the EC155 analyzer if Sensing Head Option –SH has been ordered.



Limited Warranty

Products manufactured by Campbell Scientific are warranted by Campbell Scientific to be free from defects in materials and workmanship under normal use and service for twelve months from the date of shipment unless otherwise specified on the corresponding product webpage. See Product Details on the Ordering Information pages at www.campbellsci.com. Other manufacturer's products, that are resold by Campbell Scientific, are warranted only to the limits extended by the original manufacturer.

Refer to www.campbellsci.com/terms#warranty for more information.

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Assistance

Products may not be returned without prior authorization.

Products shipped to Campbell Scientific require a Returned Materials Authorization (RMA) or Repair Reference number and must be clean and uncontaminated by harmful substances, such as hazardous materials, chemicals, insects, and pests. Please complete the required forms prior to shipping equipment.

Campbell Scientific regional offices handle repairs for customers within their territories. Please see the back page for the Global Sales and Support Network or visit www.campbellsci.com/contact to determine which Campbell Scientific office serves your country.

To obtain a Returned Materials Authorization or Repair Reference number, contact your CAMPBELL SCIENTIFIC regional office. Please write the issued number clearly on the outside of the shipping container and ship as directed.

For all returns, the customer must provide a “Statement of Product Cleanliness and Decontamination” or “Declaration of Hazardous Material and Decontamination” form and comply with the requirements specified in it. The form is available from your CAMPBELL SCIENTIFIC regional office. Campbell Scientific is unable to process any returns until we receive this statement. If the statement is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer’s expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.** FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.com. You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General

- Protect from over-voltage.
- Protect electrical equipment from water.
- Protect from electrostatic discharge (ESD).
- Protect from lightning.
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 6 meters (20 feet), or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.
- Only use power sources approved for use in the country of installation to power Campbell Scientific devices.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

Internal Battery

- Be aware of fire, explosion, and severe-burn hazards.
- Misuse or improper installation of the internal lithium battery can cause severe injury.
- Do not recharge, disassemble, heat above 100 °C (212 °F), solder directly to the cell, incinerate, or expose contents to water. Dispose of spent batteries properly.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.



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Location: São Paulo, SP Brazil
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Email: vendas@campbellsci.com.br
Website: www.campbellsci.com.br

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Location: Edmonton, AB Canada
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Email: dataloggers@campbellsci.ca
Website: www.campbellsci.ca

China

Location: Beijing, P. R. China
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Website: www.campbellsci.com.cn

Costa Rica

Location: San Pedro, Costa Rica
Phone: 506.2280.1564
Email: info@campbellsci.com
Website: www.campbellsci.com

France

Location: Vincennes, France
Phone: 0033.0.1.56.45.15.20
Email: info@campbellsci.fr
Website: www.campbellsci.fr

Germany

Location: Bremen, Germany
Phone: 49.0.421.460974.0
Email: info@campbellsci.de
Website: www.campbellsci.de

India

Location: New Delhi, DL India
Phone: 91.11.46500481.482
Email: info@campbellsci.in
Website: www.campbellsci.in

South Africa

Location: Stellenbosch, South Africa
Phone: 27.21.8809960
Email: sales@campbellsci.co.za
Website: www.campbellsci.co.za

Spain

Location: Barcelona, Spain
Phone: 34.93.2323938
Email: info@campbellsci.es
Website: www.campbellsci.es

Thailand

Location: Bangkok, Thailand
Phone: 66.2.719.3399
Email: info@campbellsci.asia
Website: www.campbellsci.asia

UK

Location: Shepshed, Loughborough, UK
Phone: 44.0.1509.601141
Email: sales@campbellsci.co.uk
Website: www.campbellsci.co.uk

USA

Location: Logan, UT USA
Phone: 435.227.9120
Email: info@campbellsci.com
Website: www.campbellsci.com